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The Magazine of Space Exploration

July/August 1990

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From the Publisher

"I believe that before Apollo celebrates the 50th anniversary of its landing on the Moon, the American flag should be planted on Mars."
— President George Bush
May 11, 1990

And when that day comes, humans and machines will both go.

I've never understood why some people see this as a conflict. We humans have been using machines to extend our reach for centuries. Trains, television, the Apollo space suit, the Voyager 2 spacecraft—all of these technologies have carried human intelligence to ever more distant places.

I have no doubt that we'll solve our "biological problem" (page 22) and that people will set foot on Mars by the president's deadline. But maybe, as Isaac Asimov wrote back in our very first issue, the people who ultimately settle space will be different from us. And maybe one of the differences will be that they'll have learned not only to live *with* robots, but *within* them (page 26).

Before anyone—man or machine—leaves for Mars, though, we have a lot of work to do. All of us, not just President Bush. We won't get off the ground by his mandate alone.

The entire endeavor is likely to cost hundreds of billions of dollars over almost 30 years. The project will come under intense scrutiny, and the critics will have a tough argument—social programs in lieu of space dollars.

To win the appropriations battles year after year, those who support space exploration will have to win on the PR front. It's elementary civics: Space exploration will have to be popular.

As a magazine, our role is simple. We can't, obviously, fire rockets. But we can fire imaginations. We at *Final Frontier* are dedicated to the idea that if we just tell people what fantastic things are happening in the world of space exploration—straight, free of jargon, in a way that everyone can understand—they'll get excited enough to see that it all continues.

As we enter our third year of publishing, we've already begun to make a difference. We're now read by more than 100,000 people with every issue. *Final Frontier* is distributed on newsstands and bookstores planet-wide. And with millions of pieces of direct-mail promotion planned over the next two years, we intend to keep fueling that growth.

So far I believe we've done a good job. *Final Frontier* readers range from astronauts to cosmonauts, entertainers to armchair explorers, seven-year-olds to ninety-year-olds.

And I can safely assume we are the only space magazine to have appeared on the TV game show *Jeopardy.*

A couple of months ago, under the category "Magazines," the answer was: "*Final Frontier* is the magazine of (blank) exploration." The question (of course) was: "What is space?" It was a 10-second impact that reached 20 million people. And for all of us in the office who did "high-fives" that day (after the contestant answered correctly), it was a welcome reaffirmation that we had indeed invaded the public consciousness.

I don't fancy myself a leader in a "cause." There are people far more qualified for that job than I am. My job is publishing the best space magazine I can—because, when all's said and done, we *all* share a responsibility if we're to realize our star-high goals.

Ever upward,

William Rooney

William Rooney
Publisher

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Letters

The Cosmic Male

Regarding your article "The Wrong Stuff" (May/June 1990): Men were first into space because it was an unknown realm and men are considered expendable, replaceable and less important than women, who are idealized and protected. In their display of grief, the media shed few tears over the male Challenger astronauts. Notice that even those feminists who want women in combat feel the women should choose it as an option and back out any time; for men, none offer any choice other than the traditional ones between combat, execution or prison. Let's hope the new frontier will bring genuine equality, and let's start by leaving out the feminist propaganda.

David C. Morrow
Men's Rights Association
Corpus Christi, Texas

Blinded by the Vision

I was dismayed with the review of Bruce Murray's *Journey Into Space* (November/December 1989). I first read the review and later the book, and I must say that the book was a great deal better than the review.

For instance, on page 257, *my* copy of *Journey* describes Carter as "the most scientifically *literate* President since Thomas Jefferson," not "illiterate" as the reviewer stated. I think that perhaps Mr. Powers read the book the way he wanted. Furthermore, I find no hint of malice on Murray's part in his treatment of Carter's decision to go with the Gamma Ray Observatory mission over a [Halley's Comet flyby] mission—though Murray was surprised when the president made such an important decision based on a popular book he was reading at the time.

Bruce Murray is not alone in claiming that what Powers facetiously calls the "evil" shuttle and the "odious" space station are problems for NASA; but at least Murray would give them a purpose—an international Mars mission—rather than dismissing them. Yes, a multi-nation Mars mission is "fashionable," but Murray is not jumping on the Mars Train; rather he, Sagan and the Planetary Society created this train.

I have other problems with the review, but when one is so blinded by the Great Shuttle/Space Station Vision, it is useless to argue. I urge others to read *Journey Into Space* for a behind-the-scenes look at NASA politics—and for the reasons why unmanned missions deserve more respect than Mr. Powers is willing to give them.

Brian Hostetler
Mishawaka, Indiana

Credit Where Credit is Due

Andrew Chaikin's feature on the Hubble Space Telescope (March/April 1990) was informative and well researched. Even so, more credit should be given to European scientists and engineers for the telescope's success.

In fact, the Hubble Space Telescope is a joint NASA/European Space Agency (ESA) project. Duccio Macchetto, who is quoted in the story, is the senior ESA staff member at the Space Telescope Science Institute in Baltimore, Maryland. The onboard Faint Object Camera was developed by ESA and was built by three European companies: British Aerospace, Dornier and Matra. And power for the telescope's instruments and control systems comes from solar arrays built by British Aerospace under contract to ESA.

Kent Olinger
Huntingburg, Indiana

Trussed Up

I have been struck by the variety of space station truss designs appearing in recent issues of *Final Frontier*. I realize that these are generally artists' conceptions, but can't we agree on a few ground rules?

The space station truss design will be driven by a need for maximum stiffness with minimum weight. Given this need, some basic features can be inferred.

1. It should be a Warren-type design in which the diagonals alternate direction. This creates the stiffest truss, but also the most complex construction joints.
2. The truss members should not be round. The stiffness of the very slender truss members would be maximized by a triangular shape. A square section would be almost as efficient and would ease construction.
3. The truss frames should have diagonal bracing. Without it, the square truss tubes would be prone to collapse.

With this in mind, check the space station renderings on pages 40-41 in the March/April 1990 issue: The computer-generated art is great, while the illustration on the same page leaves a lot to be desired.

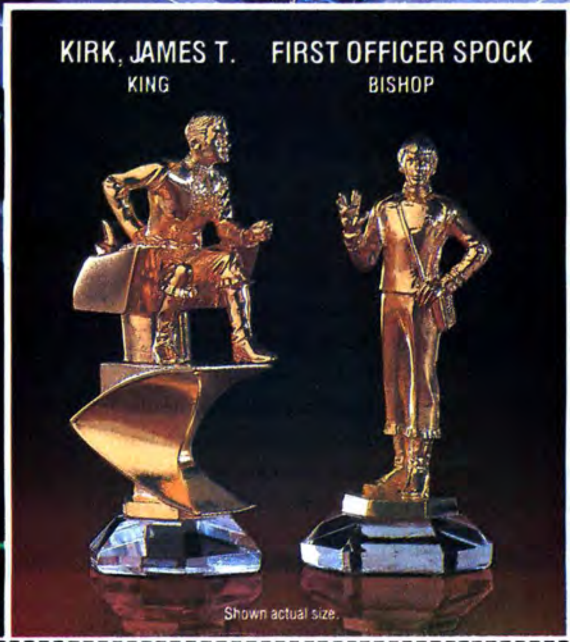
Paul R. Johnson
Houston, Texas

Facts For Fiction

I just wanted to write and let you know how terrific I think *Final Frontier* is. I am a science fiction author, and the detailed facts and firmly founded speculation I find in your magazine go straight to the core of what makes good science fiction. Your magazine will be a valuable resource for me. I wish you success and I hope you keep publishing until after the speculations described in your first issues become a part of everyday life.

Kevin J Anderson
Dublin, California

FINAL FRONTIER welcomes your letters. Send them c/o Letters to the Editor, FINAL FRONTIER, P.O. Box 11519, Washington, D.C. 20008. Please type your correspondence and limit the length to 150 words.



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The Observatory

The Galileo Effect

A new look back at Earth may show us our place in the big picture.

By Frank White

When the Apollo 8 crew made humanity's first trip to the Moon in December 1968, our thoughts were focused outward. But when the astronauts turned back to look at the Earth, and we joined them via television, something unexpected happened. Not only did we see the Moon up close for the first time, we also got an unprecedented view of the Earth from a distance.

Viewed from the Apollo capsule, the Earth was a glowing gem in the blackness of infinite space. No human had ever seen the whole planet before, a system without borders and boundaries, our beautiful home in the trackless universe. Suddenly, most people on the planet *did* get this privilege, and a major shift in human consciousness began.

This dramatic experience, which I have called "The Overview Effect," could now be reinforced by the Galileo spacecraft's encounters with Earth on its way to a rendezvous with Jupiter in 1995. NASA planners changed the original mission profile because of safety concerns and delays resulting from the Challenger accident. As a result, Galileo will require three gravity assists, one from Venus and two from Earth (in December 1990 and December 1992) in order to reach Jupiter.

The two Earth "flybys" could treat us with views of our planet (and its moon) potentially more spectacular than those achieved by the Apollo missions. Galileo will approach and photograph Earth much as the Voyager spacecraft saw the planets of the outer Solar System.

Mission planners have created many fascinating physical science experiments for Galileo's encounters with the Earth/Moon system. But the flybys could bring a new dimension to our understanding of the humanities and social sciences as well. Color photographs, later combined into a movie, may offer us yet another perspective on our planet. According to Clark Chapman, a member of the mission's imaging team, some possibilities include a "zoom" sequence of increasingly more detailed photos, views of the Earth rotating over a period of time, and "movies" of the Moon revolving around the Earth.

The view from earlier lunar and orbital missions revealed the unity and oneness not only of our planet, but also of our species. This new awareness is clearly manifesting itself in several important social patterns, including the peace and ecology movements. Revolutionary social changes have begun to sweep the planet as we move into the third decade of the "Overview Era."

The "Galileo Effect" could advance this new way of thinking about the Earth. Says Theodore Clarke, chief of the Galileo science data team, "I think the Earth encounters could provide the impulse for a transformation of consciousness toward greater love and harmony. It will help people awaken to the beauty and fragility of our planet, the infinite abundance of the Universe, and our unity with all creation."

When the astronomer Galileo turned his newly fashioned telescope toward the moons of Jupiter, it contributed to a paradigm shift known as the Copernican Revolution. Now, the spacecraft Galileo may reenact that experience in a new way some 400 years later.

Mission planners are now debating which Earth-encounter possibilities can actually be implemented. The mission's purpose is to explore Jupiter, not Earth, and there are concerns about tight funding as well as mission priorities. While these are important issues, a tremendous opportunity will have been lost if we are unable to capitalize on Galileo's two Earth encounters.

Money issues in particular might be resolved through creative financing from outside the current structure of the mission's budget. Public/private partnerships in space exploration are becoming more routine, and might be applied in this case.

One thing is certain—this opportunity should not be missed simply because we did not think it through. Before humans went into space, we could not imagine the effect those journeys would have. As astronaut Joe Allen told me when I interviewed him for my book on the Overview Effect, "With all the arguments pro and con for going to the Moon, no one suggested that we should do it to look at the Earth. But that may in fact be the most important reason."

With all the arguments pro and con over the hazards and benefits of Galileo looking our way, few have realized that it, too, could transform human consciousness—which may prove to be not only the hallmark of space exploration, but also its most profound benefit. □

Frank White is the author of The Overview Effect *and* The SETI Factor, *forthcoming from Walker and Company.*

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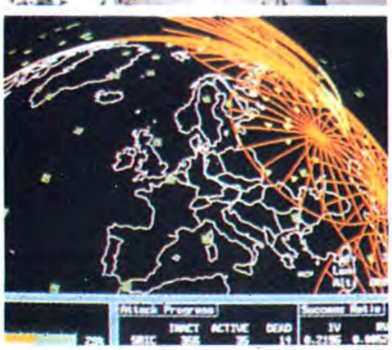

Link is also providing systems engineering and development engineering at the National Test Facility, Falcon Air Force Station, Colorado Springs, and other locations as part of Martin Marietta's SDI/National Test Bed team. The National Test Bed has been called "one of the most elaborate computer simulation networks ever developed."

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Mir and Company

New modules—and economic pressures—for the evolving Soviet space station ■ *By Peter Bond*

When the Mir space station was sent aloft in February 1986, just three weeks after the Challenger accident, it marked a new stage in the habitation of near-Earth space. The Soviets envisioned Mir becoming a permanently operating manned complex with specialized modules "designed to tackle scientific and national economic tasks." Keeping cosmonauts in orbit for extended periods was no longer good enough; this "third generation" Soviet space habitat had to start paying its own way.

Private cabins, exercise machines, new life-support systems and better ventilation promised to make living inside Mir's "core" module healthier and more comfortable than life onboard its Salyut predecessors. Meanwhile, seven computers performed much of the drudgery needed to maintain the craft. Mir's most obvious innovations, however, were the six docking ports on the outside of the station: four of them placed at 90-degree intervals around the forward transfer module, and two more at either end of the original core. These ports were crucial to the Soviets' major goal—expanding Mir into a 130-ton orbiting lab/factory complete with five add-on modules.

But this ambitious scenario, like Mir's economic potential, has proven tough to realize. While Mir's expansion is now well underway, it has gone more slowly than the Soviets had expected.

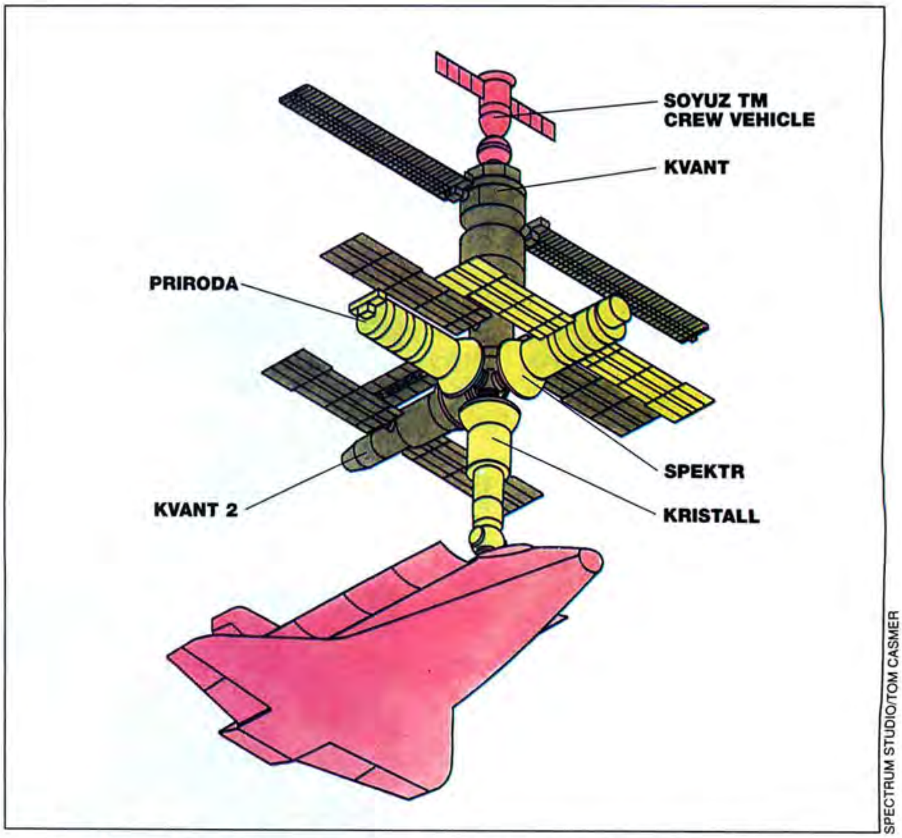
The first new module was attached to Mir's rear port in April 1987. Known as Kvant ("Quantum" in Russian), the astrophysical research facility consists of a pressurized laboratory and transfer compartment as well as an unpressurized scientific payload bay equipped with a battery of x-ray and ultraviolet telescopes.

The other modules were expected to be added at regular intervals, but more than two years passed before the second one arrived. The launch of Kvant 2, which had been rescheduled after earlier delays for mid-October 1989, was postponed once again and did not reach Mir until early December, some eight months late.

This re-equipment module, larger and heavier than the Kvant, includes a shower and improved equipment for water regeneration and oxygen production. Kvant 2 also contains a new airlock chamber that eases access to open space—a help to cosmonauts using items like the "space bike."

A few days after Kvant 2 reached Mir, a remote-controlled arm moved the module to one of the side-docking ports, temporarily giving Mir a "boot-shaped" appearance. Alexander Dunayev, head of the Soviet space agency Glavcosmos,

continued on page 10



In its final form, Mir will have five add-on modules connected to the station's central core. Kvant and Kvant 2 are already attached, with Kristall slated to arrive this summer.

Global Currents

continued from page 8

noted that the less time Mir remained in this asymmetrical configuration the better, as more fuel would be needed to keep the station in the proper orbit. But there also were worries about the stresses this unusual shape might be imposing on the craft. Dunayev said the next module—Kristall—would ideally follow Kvant 2 into space by no more than three or four months. But Kristall's planned April launch was rescheduled for June, apparently due to computer problems related to docking.

The new Kristall technological module is part of the major Soviet drive to realize a return on the country's investment in space. The cost of the latest manned expedition to Mir has been put at 80 million rubles (about $120 million), but the Soviets estimate that 105 million rubles ($166 million) could be generated, mainly through materials produced onboard Kristall. The module is defined as a "small production base" suited to producing super-pure semiconductor crystals for the electronics industry. It also will serve as a lab for conducting biotechnology experiments, Earth surveys and astrophysical research.

Kristall's arrival gives the growing Mir complex a more stable "T" configuration. The module includes its own multiple docking unit with two docking ports, one at the axial end for the Soviet Buran space shuttle, and one on the side for a scientific mini-module—a one-ton unit containing additional x-ray telescopes that will be delivered to Mir aboard an unpiloted Buran in 1991. A third, forward-facing "port" will actually be used for an optical camera system.

In March, Soviet experts revealed future plans for Mir at an international conference in Switzerland. Later this year, or in early 1991, a modified Progress supply ship will be used to return up to 330 pounds of film and experiment materials to Earth. After the Progress ship undocks from Mir, its now-loaded cargo capsule will be "pushed" out, bound for re-entry and a parachute landing. The remainder of the craft will burn up in the atmosphere.

A third lateral addition to Mir—the Spektr remote-sensing module—will probably dock with the station in late 1991. Before then, the Kristall's temporary solar panels will be folded and detached during a series of spacewalks. Using special "cranes" that cosmonauts will attach on Mir's exterior later this year, the panels will be moved to their permanent fittings on Kvant 1.

With the arrival of the 20-ton Priroda module, possibly in early 1992, the station will be complete. Priroda, say the Soviets, is designed to "explore the atmosphere and its pollution, the state of the ocean, the birth of cyclones and the state of world forests." The Priroda will arrive with only a single solar panel aligned along its axis, which may be relocated to another position on the station or simply thrown away. Priroda and Kristall will be the only two modules without permanent solar panels.

With all four lateral modules now radiating from the side docking ports like spokes in a wheel, the Buran shuttle will no longer be able to dock safely with Kristall: The risk of collision with the station's numerous solar panels will have become too great, and Kristall may have to be moved to an axial location before the Soviet shuttle can approach.

According to Leonid Gorshkov of the Energia bureau that designs the modules, Mir will probably remain in orbit until 1994. However, the first 100-ton module of the much larger Mir 2 station is not likely to be launched before 1996 or 1997. That means there may be a long interval with no Soviet space station in orbit. This may be an embarrassment at a time when the NASA/international space station Freedom should be nearly completed. However, as Gorshkov said, "Yes, there will be a gap. We don't want one...but that's life!" □

NOTES FROM EARTH

Teakettle Travel

When the British explorer James Cook made his planetary voyage in the 18th century, discovering new worlds was pretty simple. The wind propelled Cook's sailing ship, Endeavour, around the Southern Hemisphere as he tracked Venus and charted the stars in hopes of calculating the distance between Earth and the other planets.

But it'll take more than a good breeze and a sheet of canvas to propel 21st-century explorers across millions of miles of space. Robert Zubrin, a nuclear propulsion expert with the Martin Marietta Corporation in Denver, Colorado, thinks he has a solution: a rocket engine fueled by the atmosphere of an alien world. Zubrin's engine, nicknamed NIMF, for Nuclear Thermal Rocket Using Indigenous Martian Fuel, would run on the carbon dioxide in Mars' atmosphere. The rocket would "breathe" the gas, heat it with a nuclear reactor and expel it out a nozzle.

"It's basically a flying steam kettle, conceptually very simple," says Zubrin.

A probe could touch down on Mars, virtually out of fuel, and hop from point to point on the surface, collecting soil samples and refueling itself each time it lands.

In practice, this kind of engine might not be efficient enough to make it all the way back to Earth, but Zubrin claims it would be able to propel the spacecraft from the Martian surface to a rendezvous with an orbiting return ship.

"For an exploratory vehicle to have the same kind of freedom on Mars that Captain Cook had sailing the South Pacific finding islands, the NIMF is essential," Zubrin says. "This enormously multiplies the science of a Mars mission, because instead of visiting one site you can visit ten."

Zubrin's NIMF is based on nuclear propulsion technology developed in the late 1960s. Abandoned by the Nixon Administration, the prototype nuclear engines were known for their high performance. Zubrin wants to use them for their versatility. He figures they ought to work with just about any gas on any planet.

That means a spacecraft powered by a nuclear engine could leave Earth bound for virtually any destination, with its fuel tank partly full and its trunk space holding extra life-support equipment for the crew. Zubrin figures a manned Mars mission that might otherwise require six conventional heavy-lift launches from Earth could be accomplished with just one.

"Instead of [a Mars mission] being on the order of construction of the space station, where it's a national mega-project," Zubrin says, "it becomes something you can do repeatedly without any on-orbit assembly. Just light the fire and go."

—Beth Dickey

The NIMF rocket would "hop" around Mars, refueling each time it lands.

ROBERT MURRAY/MARTIN MARIETTA ASTRONAUTICS

Bugs In The System

Stargazers were understandably bugged when the countdown for space shuttle Discovery was halted minutes before liftoff on April 10, adding two more weeks to what had already been a seven-year launch delay for the $2.5 billion Hubble Space Telescope project. But for those who had to keep one of the world's most powerful astronomical tools clean while it sat in storage, the bug in the shuttle's hydraulic system wasn't nearly as pestiferous as the moths, wasps and mosquitoes at Florida's Kennedy Space Center.

Housekeeping requirements for the telescope's 94-inch mirror and sensitive cameras pushed NASA's Apollo-era cargo shelters to the limit. Even so, critters still crawled through the cracks. Workers found themselves chasing wasps with butterfly nets when they should have been installing the telescope's scientific instruments. They spent two days vacuuming gnat-like

midges out of the payload shelter on the launch tower when they should have been putting the telescope inside the shuttle.

"The stars will still be there tomorrow," said NASA astrophysicist Ed Weiler about the annoying delays. But would the telescope be able to see them?

"One pesky little moth could ruin a $70 million instrument just by being in the wrong place in orbit," fussed Bill Taylor, a fastidious engineer who entombed seven dead moths in a Ziploc bag he keeps in the bottom right drawer of his desk. An electric bug zapper sent the moths to their maker one starry night last fall, after the errant creatures fluttered into the lighted airlock of a sterile spacecraft hangar where the telescope was being delivered.

Normally, bugs are just another occupational hazard for shuttle workers, since the launch pads are surrounded by a swampy nature preserve. But for more than a year the place has been crawling with insects, and the reason why is no mystery. At NASA's request, the Merritt Island National Wildlife Refuge stopped spraying pesticides and burning brush so that super-clean instruments like the Hubble telescope and the Magellan and Galileo planetary probes would not be exposed to oily chemicals and grimy ash before launch.

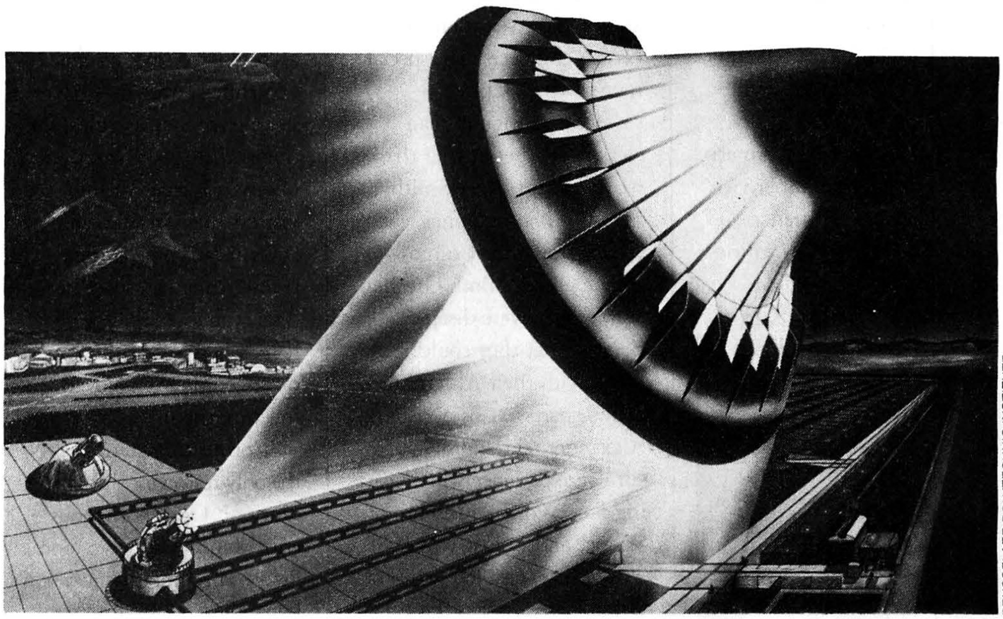
Even in its clean shelter, the space telescope stayed for five months inside a plastic cocoon that was opened only long enough for work to be done—and then only by technicians who first earned admittance by donning contamination-free clothes and combing mosquitoes out of their hair.

The hygiene hassle was apparently worth it. Technicians estimated that only 2.1 percent of the mirror's surface would be obscured—about twice as clean as the scope's designers had predicted.

—Beth Dickey

Orient Express

A laser-powered Lightcraft may be ready for tests by 1995.



RENSSELAER POLYTECHNIC INSTITUTE

New York to Tokyo in less than an hour? By the 21st century that trip could be just another morning commute, thanks to a laser-based transportation system that researchers may begin testing as early as 1995.

According to Leik Myrabo of the Rensselaer Polytechnic Institute in Troy, New York, laser-propelled travel is no sci-fi fantasy. "It's to the point that we don't expect any technological barriers," says Myrabo. His Apollo Lightcraft Project team has worked out conceptual designs for one-, two- and five-person vehicles (named Mercury, Gemini and Apollo, respectively) that they believe will revolutionize the way we travel on Earth and in space.

Six-inch scale models are currently being tested in wind and shock tunnels at Rensselaer, and a full-scale section of the engine is-being tested using a laser on loan from the Naval Research Lab. Myrabo's team plans to test-launch an unmanned drone vehicle within the next five or six years. Piloted tests could take place between 2000 and 2015, with commercial flights available thereafter.

The first tests will begin with a gunshot: An air cannon will rocket the unmanned vehicle off its launch pad much the way jet fighters are launched from the deck of an aircraft carrier. Half a second later, multimillion-watt laser beams on the ground will begin heating the air forced into the ship's engine, propelling the test vehicle upward at five to eight times the speed of sound. At 100,000 feet, the air intakes will be sealed and the lasers will heat the onboard fuel that will then drive the craft into orbit.

Launching even an unmanned drone into orbit will require free-electron lasers 10 to 100 times more powerful than those available today. Eventually, though, Myrabo believes that Lightcraft will depend on energy generated by solar power satellites in high geostationary orbit. These satellites, conceived in the 1960s, are designed to be cost-effective and competitive with current means of generating electricity. Each satellite would be capable of producing five billion watts of power—enough to handle a fleet of these ships economically. As Myrabo points out, energy is not in short supply in space.

The Air Force and the NASA/Universities Space Research Association Advanced Design Program have contributed $600,000 to the Lightcraft project over the past six years, while the Pentagon's Strategic Defense Initiative office has continued to fund laser propulsion research. All of which makes Myrabo optimistic. "It's simply a matter of time before this becomes the principal means for long-distance international travel."

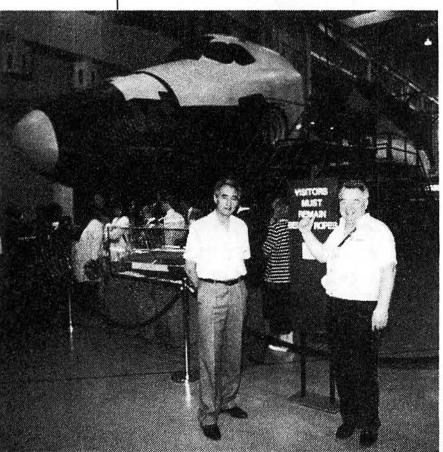
—Marion Todd White

NOTES FROM EARTH

Cosmonaut Non Grata

With the Cold War supposedly waning, American and Soviet space officials must be rolling out the red carpets for each other, right?

Well, it depends. After years of denied access, American astronauts and other visitors have recently been invited to tour space facilities in the Soviet Union ("An Astronaut in Baikonur," May/June 1990). And visiting cosmonauts, like the Soviet shuttle's chief test pilot, Igor Volk, who visited the United States last year as the guest of the American Institute of Aeronautics and Astronautics, have been greeted with open arms at NASA's Johnson Space Center (JSC). But other distinguished visitors sometimes get the cold shoulder.



BRUCE SMITH

Grechko (right) and Severin do as they're told on a visit to Houston.

In May 1989, cosmonaut Georgi Grechko and Guy Severin, chief of Soviet aeronautic safety programs, brought a Soviet space suit for permanent loan to the Kansas Cosmosphere and Discovery Center in Hutchinson, Kansas. Their U.S. itinerary included a trip to Houston, where a visit to JSC, which Cosmosphere officials reportedly had arranged, was to have included views of nonpublic areas and conversations with NASA engineers. The special tour never took place.

"A convention of mail clerks got a better tour than we did," said Bruce Smith, a freelance photographer who accompanied the Cosmosphere group. "Both Grechko and Severin were disappointed that they couldn't speak with their American counterparts." Cosmonaut Alexander Alexandrov had a similar experience while visiting Fort Worth's Museum of Science and Industry in 1988.

Charles Biggs, JSC's chief of public services, says the problem with the Cosmosphere request is that it came only a few days before the cosmonauts' visit, which didn't allow enough time for proper handling. "Typically, NASA headquarters has shown a fairly firm line against showing Soviets anything other than what the public sees," said Biggs. The public sees the auditorium, the shuttle training facility, the lunar sample processing facility, an outdoor rocket park and, during non-flight periods, the mission control center. A VIP tour might include "access to trainers, space-station mockups, in-depth briefings and discussions with technical people," Biggs said.

He emphasized that NASA's restrictive policies aren't confined to the Soviets. "They apply to any foreign nationals, including those from Canada and Mexico."

Exceptions are made "when approved through proper channels," he said, and depend to a degree on the Soviets' willingness to follow those channels, which can include negotiations with embassy personnel and the NASA Office of International Affairs in Washington. Cosmonaut visits to JSC now number two or three a year, according to Biggs.

While NASA may have good reason for its rules, the unfortunate result, says one observer, is that distinguished visitors like Grechko and Severin can come and go before American space officials even learn they were here, when in fact the Americans would have enjoyed meeting them.

Is protecting state secrets the only reason for this official caution? One anonymous critic thinks otherwise: "Some low-level bureaucrats just don't know the Cold War is over."

—*Mary Campbell Nielsen*

Cooking with Glass

If you live in a glass house, you shouldn't throw stones. But it's okay to melt them—or so says a New Mexico nuclear engineer who has figured out how to turn rocks on the Moon into ceramic building blocks.

A microwave oven is all you need, says Steven Howe, chief of space technology programs at Los Alamos National Laboratories. Seeking ways to build a lunar base without sending construction supplies up from Earth, Howe and a team of scientists and university researchers envision a city built with glass baked from Moon soil in a microwave oven.

"We'll need tools with few moving parts in order to reduce our dependence on Earth and increase our independence at a lunar base," says Howe. "And microwave processing fits."

As Howe explains it, bricks would be the by-product of an operation to extract valuable elements from lunar soil. When the dirt is heated, gases such as hydrogen and helium boil off. The gases are condensed and collected for later use as ingredients in water and fuel.

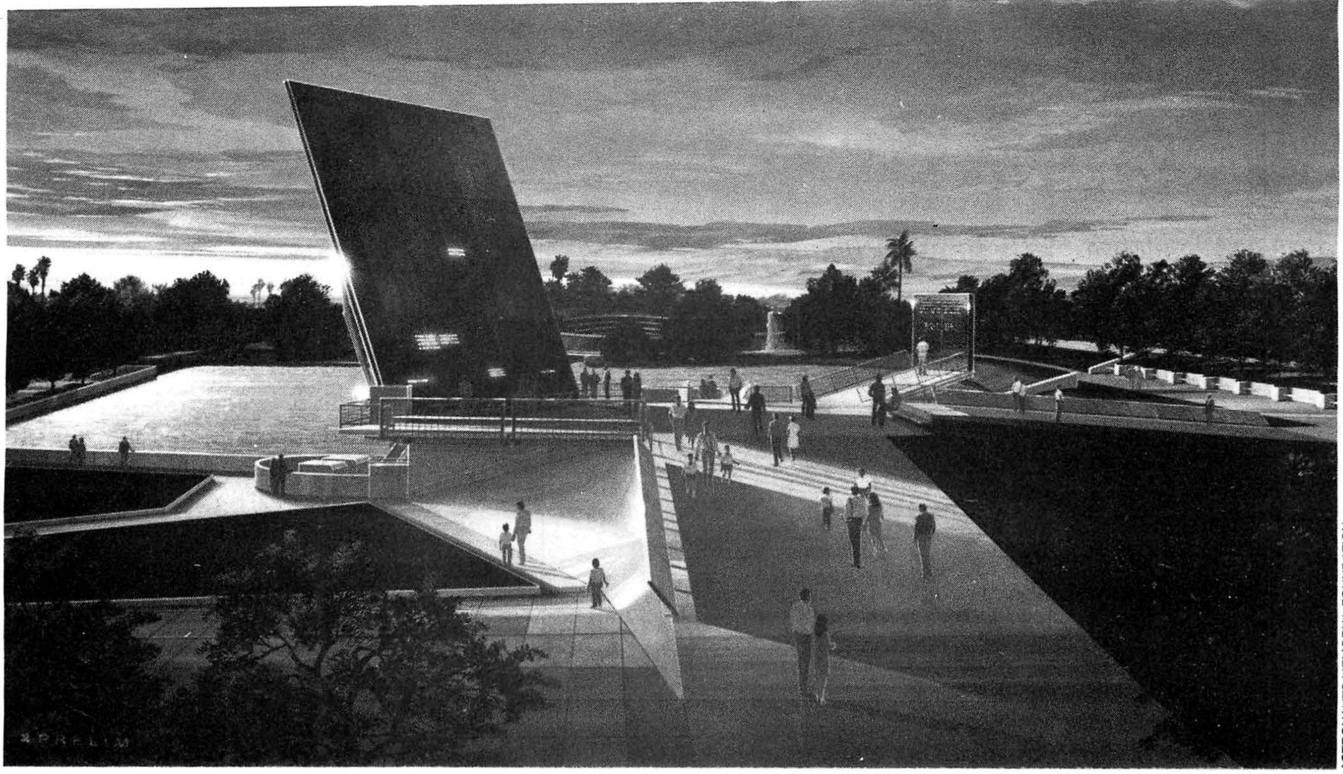
"You can mold [the lunar dirt] into any shape you want, put it in the microwave, let it get red-hot and turn into a liquid," Howe says. "You can turn it into a black glass if you cook it long enough."

Howe thinks it might even be possible to make the glass translucent by removing certain elements from the soil: "You could have a sunny habitat instead of a cave, and from a psychological standpoint, that will be important."

The Los Alamos microwave technologists have experimented with real lunar soil samples, although most of their work has been with simulants made from terrestrial dirt.

But don't try this at home. The Los Alamos ovens are four times more powerful than a household microwave. "These aren't just off-the-shelf kitchen appliances," Howe warns. "These will blow your potatoes up."

According to the scientists' calculations, brick-making in a microwave oven takes one percent of the time and ten percent of the energy of a



ASTRONAUTS MEMORIAL FOUNDATION

conventional furnace. The success of the experiments has prompted the scientists to think about putting the technology on wheels.

"We envision a microwave cart driving, heating up the soil to suck out and store the gases, and making a hard, ceramic surface as it goes," Howe says.

Lunar highways are a long way off, but microwave paving is an immediate solution to the troublesome dust that Moon base development would be likely to stir up.

"Moon dust is extremely fine, very corrosive, and it gets everywhere," Howe explains. "This would keep you from kicking it up and ruining your expensive equipment."

Developing the microwave technology would cost no more than $10 million, according to Howe. The Los Alamos team has neither designed nor figured the cost of a microwave rover. But the scientists have proposed a $5 million rover test facility as the foundation for a $30 million simulated "Moon base" in New Mexico.

—Beth Dickey

Mirror, Mirror

The Astronauts Memorial should be catching sunlight by year's end.

Work has begun at Cape Canaveral on The Astronauts Memorial, a $7.8 million project to honor American astronauts who have died in the quest to explore space. According to plans, the unique "Space Mirror" structure and its computer-driven solar tracking system should be catching sunlight by the end of the year.

The campaign to build some sort of tribute to fallen astronauts began shortly after the Challenger accident in January 1986, when Alan Helman, an architect, founded the Florida-based Astronauts Memorial Foundation (AMF). Helman approached the Florida legislature for assistance, and within months the lawmakers had passed a bill permitting the creation and sale of a commemorative Challenger license plate. The public response was overwhelming.

"The Challenger plate raised $11 million," Helman proudly said. A later modification in the program allocated $5.3 million of the $5.8 million needed to design and build the memorial. Corporate donations brought in half a million more.

NASA, meanwhile, set aside six acres for the memorial at Spaceport USA, on the grounds of the Kennedy Space Center. Though the land will remain NASA property after the memorial is completed, an additional $2 million endowment from the AMF will be used to insure its care and upkeep.

Even though Helman is an architect, he did not design the memorial. The AMF sponsored a national design competition whose 756 entries were assessed by an independent panel of judges in early 1988. The winning "Space Mirror" concept came from the San Francisco-based architecture firm of Holt Hinshaw Pfau Jones.

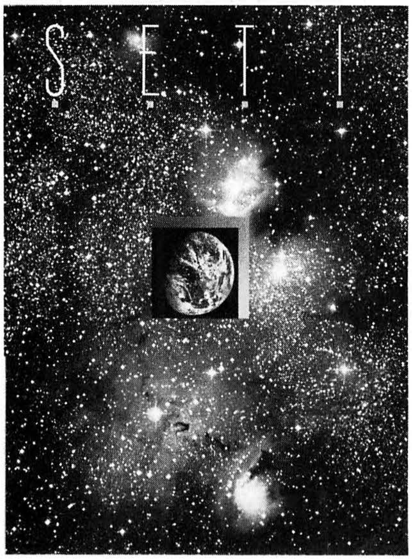
The completed memorial will be a rectangular plane of highly polished granite slabs, 42.5 feet high by 50 feet wide, with the names of 14 fallen astronauts cut stencil-like through its surface. This structure will be supported by a turning frame that will track the Sun each day, providing a constant reflection of the sky. The astronauts' names will appear to blaze on this field, as light from a separate system of mirrors is caught and diffused within the glass filling each carved letter. Artificial lighting will illuminate the names on cloudy days and at night.

Helman expects the Space Mirror to be completed and dedicated in December 1990. Listed on the memorial will be Challenger crew members Francis "Dick" Scobee, Michael Smith, Ronald McNair, Ellison Onizuka, Judith Resnik, Gregory Jarvis and Christa McAuliffe; Apollo 1 crew members "Gus" Grissom, Edward White and Roger Chaffee, who died in the 1967 launch pad fire; and Theodore Freeman, Charles Bassett, Elliot See and Clifton Williams, who were killed in T-38 training accidents.

—Joseph Baneth Allen

Reviews

The NASA Bookshelf ■ *By Tony Reichhardt*



The U.S. Government Printing Office cranks out more titles than any publisher in the world, and in the past, NASA publications have always been right up there among its best-sellers. That's probably because, let's face it, any person with a still-beating heart would rather read about the space station than about the latest soybean production figures presented to the legume subcommittee of the Senate agriculture committee.

But it may also be because NASA's books, posters, lithographs and brochures are generally attractive, informative and modestly priced. And, as they say in the commercials, they aren't available in stores.

For history buffs, there are the agency's "official" accounts of the glory projects of the 1960s and 1970s. The most recent addition to this NASA History Series, which in the past has chronicled the Mercury, Gemini, Apollo and Skylab programs, is a 1989 history of the Apollo lunar explorations, *Where No Man Has Gone Before* (GPO Stock Number 033-000-01047-8; $19). Like the others in the series, this is an academic work, complete with footnotes explaining which project official sent what memo to whom on May 3, 1967. Don't expect style, but there's a lot of good information.

If you want a lighter, more colorful account of the Apollo 11 flight, try *The First Lunar Landing* (033-000-01054-1; $2.50), a transcript of Armstrong, Aldrin and Collins' post-landing press conference, backed by sharp color photos from the mission. NASA reprinted this 24-page 1970 booklet last year to mark the 20th anniversary of the flight.

You'll find more nostalgia in *A Meeting With the Universe* (033-000-00836-8; $14), a full-length book summarizing science discoveries from the first two decades of the space program, published in 1981. The writing, by a team of NASA scientists, is unexpectedly graceful, and the photos are spectacular.

Future plans for space transportation are outlined in *Round Trip to Orbit: Human Spaceflight Alternatives* (052-003-01155-7; $5.50). This 117-page report is listed in GPO's NASA bibliography, even though it was produced by the Office of Technology Assessment (which, like the National Academy of Sciences, turns out several reports on the space program each year). Despite the government-gray format, there's a lot of solid background on such projects as the National Aerospace Plane and the proposed Shuttle-C cargo vehicle.

SETI (033-000-01059-1; $3.75) is typical of the well-designed color brochures NASA publishes for just about all its major projects: 32 pages of illustrations and text explaining in straightforward, layperson's terms what scientists searching for signs of extraterrestrial civilization hope to find, and how they hope to find it. *Space Shuttle: The Renewed Promise* (033-000-01034-6; $2) was written after the 1988 flight of Discovery that returned American astronauts to space nearly three years after the tragedy of Challenger. This glossy 24-pager is more PR than new information, but the pictures are nice.

Along with brochures, GPO has wall-sized NASA posters for sale. A recently published Space Suit Wallsheet (033-000-01067-2; $5.50), showing a cutaway view of an astronaut in the artificial cocoon of a space suit, is particularly dramatic.

Another good bet, if you're interested in Earthly benefits from the space program, is the annual *Spinoff* (033-000-01069-9; $9.50) volume that details a surprisingly large number of space-derived ideas, gadgets and technologies that have made it out into the private sector.

For my money, though, NASA has yet to top the *Voyager Neptune Travel Guide* (033-000-01056-7; $12). Written before last year's Neptune flyby, this entertaining hodgepodge of gee-whiz facts, thorough yet understandable explanations of all the science experiments onboard, and fold-out maps (there's even a "flip-movie" that shows Voyager 2's progress through the Neptune system as you riffle quickly through the pages) is probably the best book published on the Voyager missions to date.

It rarely happens, but in this case NASA may have outdone the commercial publishers and produced something worthy of a *real* best-seller list. □

Ordering NASA Publications

To order the publications mentioned here, write to:

Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

Be sure to include the GPO stock number and payment with your order, and expect to wait as long as four weeks for delivery. Speaking of waiting, you can also try calling the GPO's order/information desk at (202) 783-3238, but don't be surprised if you get a busy signal.

For a more complete listing, ask for GPO's Subject Bibliographies related to space. SB-257 covers NASA scientific and technical publications, and SB-222 covers NASA educational publications.

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Space Shuttle Launch Schedule

All dates are subject to change.

Secret Military Mission

Flight:	Launch Date:	Orbiter:	Duration:	Orbital Altitude:	Crew:
STS-38	7/9/90	Atlantis	4 days (reported)	165 miles 28.45 degrees inclination (reported)	CDR: Richard Covey PLT: Frank Culbertson MS: Robert Springer Carl Meade Charles Gemar

Highlights:

Culbertson, Meade and Gemar are all making their first flights on this classified military mission.

Life Science Spacelab

Flight:	Launch Date:	Orbiter:	Duration:	Orbital Altitude:	Crew:
STS-40	8/29/90	Columbia	9-10 days	150 miles, 39 degrees inclination	CDR: Bryan O'Connor PTL: Sidney Gutierrez MS: Rhea Seddon James Bagian Tami Jernigan PS: Drew Gaffney Millie Hughes-Fulford

Highlights:

This first Spacelab mission in five years is also the first devoted entirely to space medicine and biology. A mixed team of scientists and astronauts will spend nine days studying how zero-g affects bones, muscles, heart, lungs, balance organs and virtually every other system in the human body. Also onboard will be jellyfish and nine rats, who'll be tested for their response to spaceflight. The Spacelab adds an extra "room"—actually a fully equipped lab—connected by a tunnel to Columbia's crew cabin. Earlier Spacelab missions were divided into two shifts, but Gaffney, Seddon, Bagian and Fulford will all work the same schedule inside Spacelab,while O'Conner, Gutierrez and Jernigan tend to shuttle systems. Out in the cargo bay will be the first Getaway Special payloads of the post-Challenger era. These small, cheap, experiments-in-a-can will be mounted on a new kind of "bridge" that can hold a dozen canisters. If fuel and other consumable supplies hold out, flight directors may choose to add an extra day to the nine-day mission.

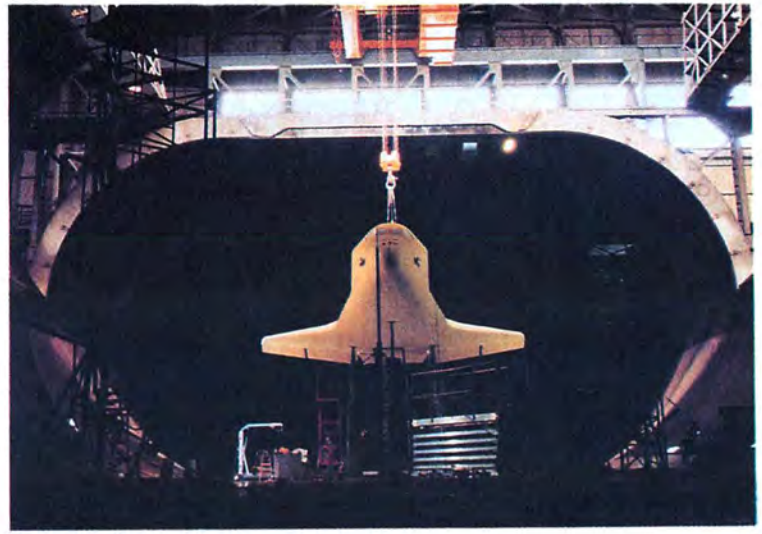
Ulysses To The Sun

Flight:	Launch Date:	Orbiter:	Duration:	Orbital Altitude:	Crew:
STS-41	10/5/90	Discovery	4 days	160 miles, 28.5 degrees inclination	CDR: Richard Richards PLT: Robert Cabana MS: William Shepard Bruce Melnick Thomas Akers

Highlights:

Scientists know a great deal about the Sun's middle latitudes, but the European Space Agency's Ulysses will be the first probe to explore its polar regions. Six hours into the flight, mission specialist Tom Akers will flip a switch to release Ulysses from the shuttle cargo bay and send it on its way toward Jupiter, where it will pick up enough gravitational energy to swing under the Sun's south pole in 1994, then up and over the north pole in 1995. Ulysses will give scientists their first 3-D view of the complex fields and particles streaming from our local star. Except for Richards and Shepard, this will be an all-rookie crew. Melnick and Akers are the first from their 1987 astronaut class to fly, and Melnick will be the first Coast Guard officer in space. The crew will try out some new tricks after Ulysses is safely on its way. They'll test a new fiber-optic communication system to see how light signals transmit through shuttle windows under different lighting and temperature conditions. They'll also check out a new system for voice-controlled operation of TV cameras in the cargo bay. Wearing lightweight headsets, the astronauts will see if the cameras respond to their commands after programming an onboard computer with their individual voices pre-flight. Shades of "HAL".

Title Abbreviations: CDR: Commander PLT: Pilot MS: Mission Specialist PS: Payload Specialist



Gamma Ray Observatory

Flight:	Launch Date:	Orbiter:	Duration:	Orbital Altitude:	Crew:
STS-37	11/3/90	Atlantis	5 days	243 miles, 28.5 degrees inclination	CDR: Steven Nagel PLT: Kenneth Cameron MS: Jerry Ross Jay Apt Linda Godwin

Highlights:

On its fortieth flight, the shuttle delivers the second of NASA's "Great Observatories" into orbit. The Gamma Ray Observatory (GRO) will explore a little-known region of the spectrum, looking for clues to high-energy processes in stars. The spacecraft is big and bulky: Gamma rays don't trap easily, and the four detectors weigh as much as two tons each. The payoff will be an all-sky survey with up to 20 times the previous sensitivity for gamma rays. GRO is dropped off into orbit two days into the flight. Then, on the following day, comes the first U.S. spacewalk in five years, when Apt and Ross go outside to test a new mobility system designed for space station Freedom—a kind of railroad handcar with three different means of locomotion. During their six hours outside, the astronauts will check out the equipment and carry each other around piggy-back to simulate moving around with a heavy load in tow. It's a high orbit, and the spacewalkers should have a good view of the curving Earth below. In his off-duty hours, pilot Ken Cameron will communicate with amateur radio operators on the ground.

International Microgravity Lab

Flight:	Launch Date:	Orbiter:	Duration:	Orbital Altitude:	Crew:
STS-42	12/12/90	Columbia	9-10 days	167 miles 28.5 degrees inclination	CDR: Ronald Grabe PLT: Stephen Oswald MS: Manley Carter Norman Thagard William Readdy PS: Ulf Merbold Roberta Bondar

Highlights:

Quiet is the watchword on this dedicated Spacelab mission, which is evenly divided between life science and materials science experiments sponsored by more than 200 scientists in 13 countries. The shuttle will hold its thruster firings to a minimum, and will orbit with its tail pointed at the Earth to provide the smoothest possible ride for sensitive crystal growth studies. The crew will be divided into two shifts for round-the-clock operations: The "Blue" team of Oswald, Thagard and Bondar will sleep while the "Red" team of Grabe, Readdy, Carter and Merbold works. Space sickness expert Bondar is the first non-U.S./non-Soviet woman to fly in space, and West Germany's Merbold returns to orbit after a six-year absence. The crew will film highlights of their trip with a large-format IMAX camera, and a full complement of 12 "Getaway Special" experiments will be riding in the cargo bay. The mission may be extended by a day if all's going well.

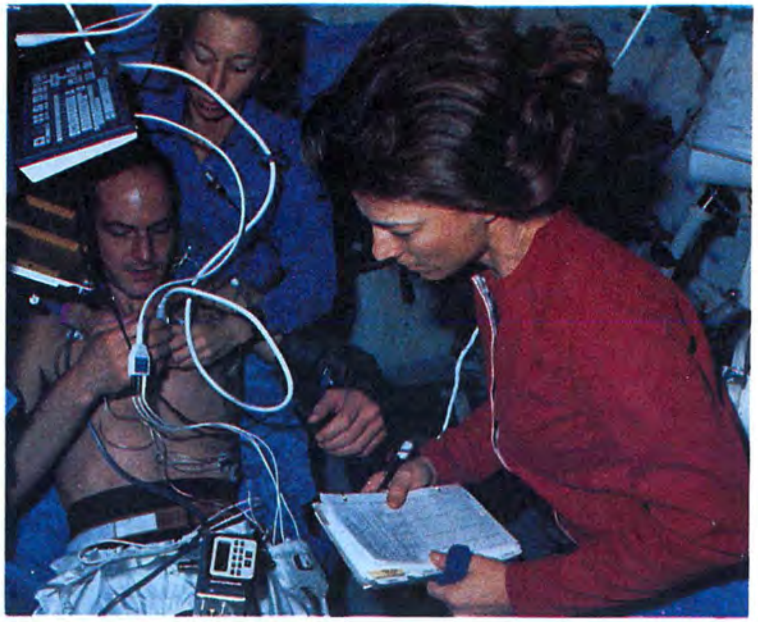
Defense Research Mission

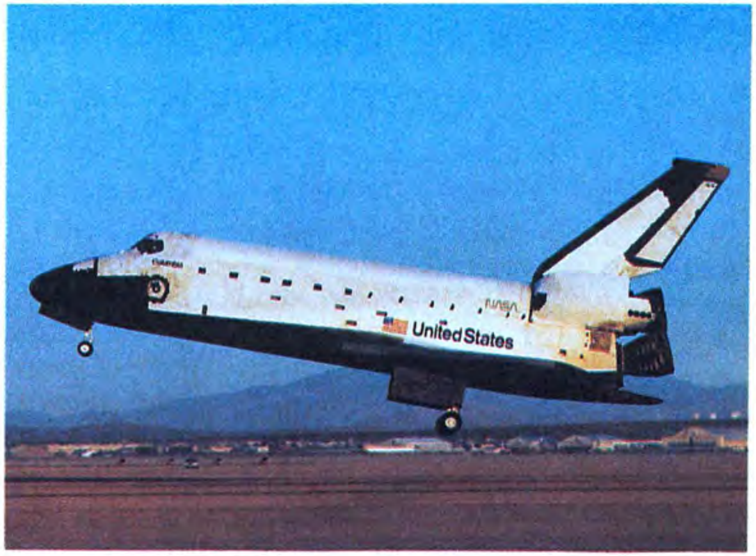
Flight:	Launch Date:	Orbiter:	Duration:	Orbital Altitude:	Crew:
STS-39	1/31/91	Discovery	8 days	140 miles, 57 degrees inclination	CDR:Michael Coats PLT: Blaine Hammond, Jr. MS: Guy Bluford Richard Hieb Charles Veach Gregory Harbaugh Donald McMonagle

Highlights:

This flight started out as STS-39, then was changed to STS-51, and is now back to STS-39 again. The mission, though, has always remained the same—to conduct as many defense-related experiments as seven busy astronauts are able to cram into eight days of dual-shift, round-the-clock operations. The mixed bag of unclassified experiments includes several investigations of the infrared environment around the shuttle. In one test, a German-built SPAS platform will be set free to orbit at a distance from the shuttle, while instruments on the SPAS record the firing of Discovery's orbital maneuvering engines. For a military-sponsored flight, the crew is surprisingly ecumenical: Hieb, Veach and Harbaugh are all civilians. Only Coats and Bluford have flown before.

Produced by FINAL FRONTIER: The Magazine of Space Exploration





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MISSION FILE

STS-31

LAUNCH:
8:33 a.m. EDT, April 24, 1990
Pad 39B, Kennedy Space Center, Fla.

LANDING:
6:49 a.m. PDT, April 29, 1990
Edwards Air Force Base, Calif.

ORBITER:
Discovery

ALTITUDE:
311-333 nautical miles

CREW:
Loren J. Shriver, Commander; Charles F. Bolden, Jr., Pilot; Bruce McCandless II, Steven A. Hawley, Kathryn D. Sullivan, Mission Specialists

PRIMARY PAYLOAD:
Hubble Space Telescope

OTHER PAYLOADS:
Protein Crystal Growth; Investigation Into Polymer Membrane Processing; IMAX cameras; Student experiment 82-16 (Ion Arc); Ascent Particle Monitor; Radiation Monitoring Experiment

No doubt about it, STS-31 was NASA's Big Show. Over the years, the $1.5 billion Hubble Space Telescope nestled in Discovery's cargo bay had generated at least its own weight in slick brochures, gee-whiz fact sheets and paeans to its potential for revolutionizing astronomy. But now, as one NASA wag put it, it was "time to brew."

On April 10, NASA scrubbed its first STS-31 launch attempt just four minutes before liftoff when one of Discovery's three auxiliary power units (APUs) went haywire. Among the disappointed shuttle-watchers at the Cape were 50 Hubbles, Hubbels and Hubbells—near and distant relatives of pioneering astronomer Edwin P. Hubble, for whom the first of NASA's "great observatories" was named.

After technicians replaced the offending APU on the pad (a first) and recharged the space telescope's six nickel-hydrogen batteries, shuttle managers set April 24 as the new launch date.

DAY ONE

At T-31 seconds, the countdown slammed to a halt when a liquid oxygen fill-and-drain valve onboard Discovery stuck open. Controllers quickly recognized the problem as a computer software foul-up, commanded the valve to close and cleared the mission for launch.

The shuttle painted a familiar picture as it arced away into the Florida skies, but this ascent was intentionally a bit different. The STS-31 crew was bound for the highest shuttle altitude ever, so its trajectory was faster and steeper than prior missions. The unique flight profile let the astronauts pass some of their abort milestones up to a minute earlier than normal and gave them an unusual abort site at Hoedspruit Air Base in South Africa.

Discovery's crew wasted no time getting ready for the next day's deployment of the Hubble Space Telescope.

The telescope undergoes a checkout while still in the cargo bay.

Steve Hawley powered up the shuttle's mechanical arm and used its cameras to inspect the telescope's gleaming, aluminized outer surface. Bruce McCandless and Kathy Sullivan breathed 100 percent oxygen from their helmet assemblies while the orbiter's cabin pressure dropped from 14.7 to 10.2 pounds per square inch (psi). The "prebreathing" procedures would shorten the time required for McCandless and Sullivan to prepare for a spacewalk if any serious Hubble trouble cropped up.

Sullivan later unpacked STS-31's other "crew member," a human skull filled with thermoluminescent radiation-measuring instruments. The "Phantom Head," flown aboard two previous shuttle missions, adorned the orbiter's right-hand wall for the rest of the high-altitude flight.

DAY TWO

At first, Hubble deployment operations went off without a hitch. Hawley gingerly raised the 24,000-pound instrument from Discovery's payload bay while mission specialists McCandless and Sullivan prepared for a spacewalk they hoped wouldn't be necessary.

The first hint of trouble came when Hubble's two solar array arms failed to trip microswitches that signaled full deployment. Precious minutes ticked by—the telescope had only eight hours of battery life without a recharge—before flight controllers gave a "go" to begin unrolling Hubble's solar cells.

The left-hand solar panel unreeled as planned. Then the right-hand array unlatched, rolled out a single segment on each side...and stopped.

While the Hubble specialists at NASA's Goddard Spaceflight Center in Maryland scrambled to work around the problem, McCandless and Sullivan completed another 40-minute prebreathing session, then depressurized Discovery's airlock down to five psi. Just before they would have opened the hatch to go outside, Hubble controllers finally got what they were looking for: the recalcitrant solar cells deployed.

Before turning in, Sullivan opened a valve to activate the Investigations into Polymer Membrane Processing experiment. On Earth, industry uses polymer membranes to filter and purify a variety of substances. Gravity, however, sets up convection currents that influence the membranes' structure as they form by evaporation. Researchers hoped to find out what effect the lack of convection, a result of zero-g, has on such

Top: McCandless, Hawley and Shriver watch the action overhead. Above: Fish-eye view of Sullivan and Hawley in the mid-deck.

"We see motion," radioed Mission Control in Houston.

"We see it too!" responded one of the astronauts.

As Discovery glided over the South Pacific near the coast of Ecuador, Hawley unlatched the robot arm's end effector, or hand, and the Hubble Space Telescope finally was set to drift alone in the orbit where it will spend the next 15 years or so.

membranes during casting.

Sullivan and McCandless also checked another mid-deck payload, the Protein Crystal Growth experiment, a variation on the apparatus that flew aboard three other post-Challenger missions. On STS-31, 60 different investigations were done simultaneously, using 12 different proteins. By studying the three-dimensional structure of the space-grown crystals, which generally are purer than those obtainable on Earth, scientists believed they may find the key to new or improved drugs.

DAY THREE

The schedule was purposely light for Discovery's crew on the day after Hubble deployment. The astronauts spent much of their time doing what tourists anywhere do—they took pictures. Among the targets for their large-format IMAX movie cameras were Japan, the Andes, the Amazon Basin and San Francisco Bay.

They had a spectacular, unprecedented view. "Three thirty is a whole lot higher than 120 was," Kathy Sullivan had remarked earlier as she compared Discovery's altitude to her 1984 Challenger flight. "I don't know how much longer it takes [to reach a particular spot], but every second of the wait is worth every second you get."

The highlight of the astronauts' third day in space was their work with a student experiment to observe what an electric arc does in weightlessness. Television views showed the arc resembled a continuous lightning bolt. It moved, but didn't travel up and down as it would on the ground, exactly as Utah State student Gregory Peterson had predicted.

DAY FOUR

Humor kicked off the spacefarers' day as they showed off an unexpected "find": a watch lost by astronaut Sonny Carter on Discovery's STS-33 flight last November. The timepiece apparently had lodged behind one of the cabin's myriad instrument panels where, incredibly, it

remained undetected until it floated out in zero-g.

Discovery's crew was up early to support the critical opening of the aperture door at Hubble's front end. If the cover failed to reach its full 105-degree position, mission specialists Sullivan and McCandless were to don their spacesuits and attempt a fix-it job.

Hubble had been skittish since deployment. Controllers at Goddard had struggled to keep communications links and the mighty telescope already had shut itself down once thanks to a spurious gyro reading.

The first effort to open the aperture door fizzled. An out-of-limits movement by one of Hubble's high-gain antennas put the telescope into a "safe mode," a sort of preprogrammed electronic limbo. On the second try, the 10-foot-wide cover mercifully swung up and out.

"Discovery, Hubble is open for business!" crowed astronaut Story Musgrave from Mission Control.

"I don't suppose they'd want to give me any [observing] time on it, would they?" joked Steve Hawley, a trained astronomer.

Mission Control released the crew from escort duty

The crew: Bolden (top), Shriver, Sullivan, McCandless and Hawley.

even though there were still problems with Hubble's high-gain antennas. McCandless and Sullivan had trained to support deployment activities, but an unscheduled repair call wasn't on their agenda. Just as important, Houston wanted to preserve the orbiter's supply of "consumables"—oxygen, food and maneuvering fuel—that would be required to keep Discovery in orbit for weather-related landing delays.

During a lively telecast around midday, Sullivan and Hawley showed off a memento they had brought along: an eyepiece that

Free of the cargo bay, Hubble prepares to spread its solar wings.

Edwin Hubble himself had used on the 100-inch Mt. Wilson Observatory telescope.

That evening, Discovery left its valuable charge behind for good as it passed beneath the higher-flying telescope. It wasn't even a tearful farewell. The astronauts were asleep.

DAY FIVE

The STS-31 crew spent a routine day before homecoming, packing up equipment and testing Discovery's flight control surfaces and thrusters prior to reentry. The only mechanical glitch was a failed fuel pump heater on one of the orbiter's APUs. The crew turned on a backup unit that performed properly.

In a televised news conference, the astronauts beamed about the mission's meaning for astronomers, both present and future. "It's hard to find someone who's never heard of the Hubble Space Telescope," said pilot Charlie Bolden. "It makes little kids want to learn how to add and subtract and study science."

Meanwhile, Hubble controllers continued to troubleshoot the high-gain antenna gimbaling problem; a bulging electric cable emerged as the likely culprit.

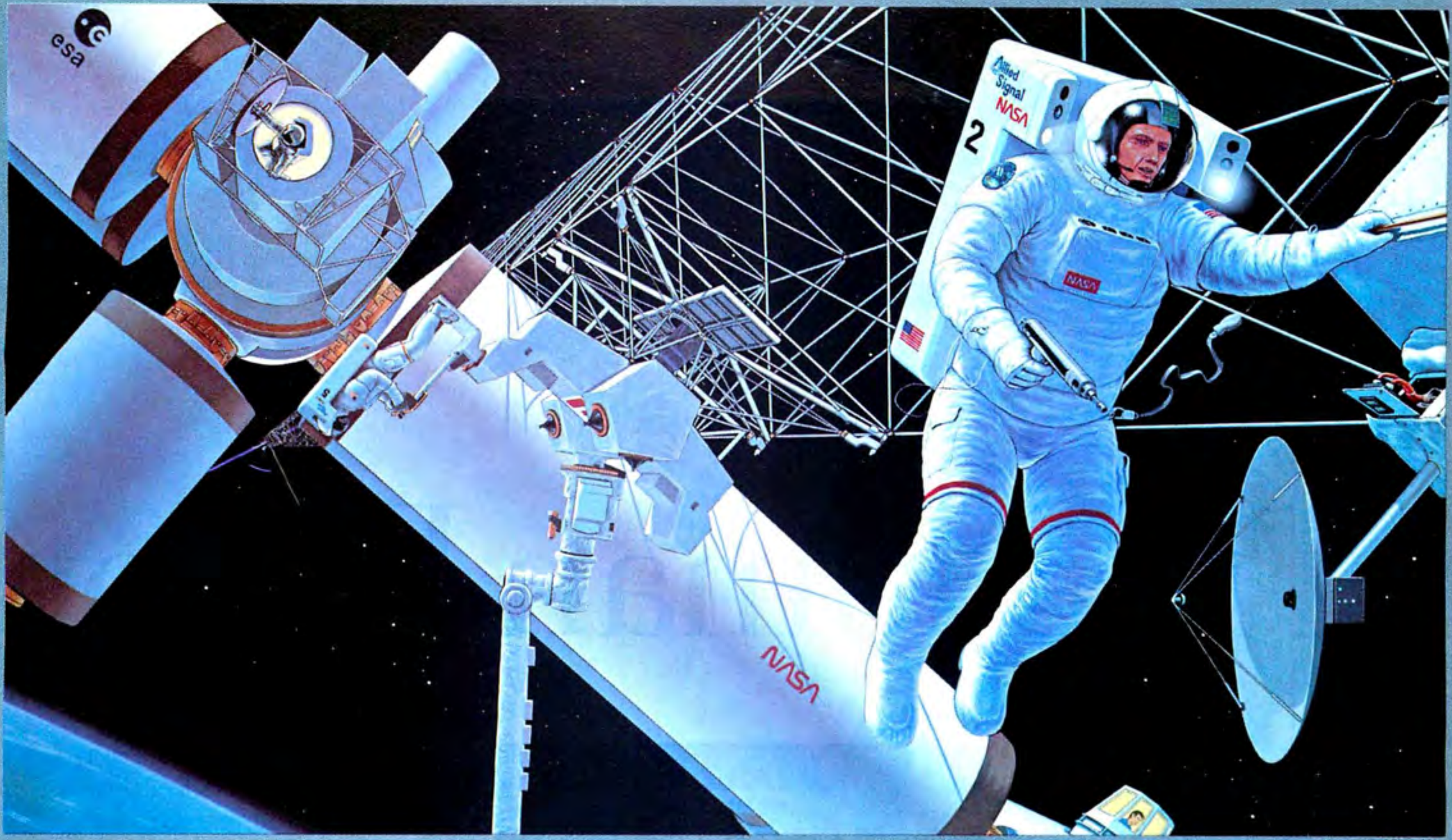
DAY SIX

Over the Indian Ocean, Discovery's twin Orbital Maneuvering System rocket motors fired to start the longer-than-normal journey from its record altitude. The duration of the burn (4:49) was the longest in shuttle history.

High winds at Discovery's Edwards Air Force Base landing site prompted a minor shift in the orbiter's aiming point from Edwards' long dry lake bed to concrete Runway 22. The rising sun glinted off the orbiter's broad bottom as Discovery swept over the air base and made a long, sweeping turn to line up with the runway.

About 20,000 earlybirds watched the spaceplane make a perfect touchdown, then roll nearly 9,000 feet as Shriver and Bolden gently but steadily applied pressure to Discovery's new carbon-carbon brakes. The old shuttle brake design had a disturbing habit of falling apart under even normal stress. The tougher carbon-carbon assemblies eventually may allow crews to resume landings at the Kennedy Space Center shuttle strip, shaving several days off the time required to refit orbiters for flight.

Before the five STS-31 crew members returned to Houston for several days off, Charles Bolden summed up their mood about the Hubble telescope's future. "You won't see anything for a week, you won't see anything for a month," he said, "but over the next few months and the next few years, you're going to see some absolutely *amazing* things." □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We know what happens to astronauts in Earth orbit, but the rest of space is still uncharted territory. By Devera Pine

The Human Factor

The engineering problems are well understood, or at least most of them. Before sending astronauts to explore other worlds, we'll need to develop advanced computer programs and life-support systems, work up housing for lunar colonists, develop new power sources and design propulsion systems to carry crews to Mars and back. More than likely, engineers will be able to meet these demands within the next 20 years. But one factor in the race to leave Earth is often overlooked: We may have the technology to explore space, but do we have the biology?

Right now most experts, at least in the United States, would answer no. Even if the hardware problems were already solved, we wouldn't risk sending humans to Mars. From a medical point of view, there are serious drawbacks to living and working in space. There are the purely physical effects of life without gravity: Bones lose calcium, muscles atrophy, body fluids shift upward, the cardiovascular system deconditions and the immune system powers down. Plus, about half of all astronauts who go into orbit experience the temporary discomfort of space motion sickness.

In addition to these well-documented physical changes on short orbital flights, there are medical problems with a flight to Mars that would arise simply from living in space for years at a stretch: how to keep viruses and germs from running rampant in the closed environment of a spaceship; how to perform emergency surgery in weightlessness; and how to keep a crew psychologically healthy on a two- to three-year round trip to Mars.

Most significant of all may be the unknown dangers posed by radiation: Solar flares and cosmic radiation could cause genetic damage, cancer and even death to space travelers. How to protect against these hazards? We aren't yet sure. But all these questions will have to be answered before we venture out beyond the relative safety of Earth orbit.

The physical changes the body undergoes in weightlessness are probably the most well-known medical aspect of space travel. They may also be the least problematic. In zero-g, bones and muscles don't have to hold the body upright, so they lose mass. Researchers don't know the exact rate of loss, but the change occurs as soon as an astronaut gets into space. Fur-

thermore, says Frank Sulzman, chief of NASA's space medicine and biology branch, no one knows whether the loss of bone and muscle continues for as long as the astronaut is in weightlessness or whether it stabilizes and stops at some point.

On long missions to Mars, the bone loss might be a particular problem: Thin, weak bones might be more likely to fracture when exposed to the stress of gravity on Mars, says Harry Holloway of the Uniformed Services University in Bethesda, Maryland, who chairs the aerospace medicine committee that advises NASA.

Other back-to-gravity problems would occur when the first astronauts landed on Mars. Their hearts would be unused to pumping blood against the pull of gravity. They might be dehydrated, dizzy or lightheaded due to the upward shift of body fluids that takes place in zero-g. The body interprets that shift as a sign that there's too much water everywhere, so it signals the kidneys to excrete the extra water. As a result, astronauts can experience a two to three percent decrease in blood volume: Upon returning to gravity, the fluid shifts back to the legs, and the low blood volume can cause faintness.

As for the nausea and vomiting of space motion sickness, that's unlikely to be a significant problem for Mars-bound

Pete Conrad on Gemini 5 in 1965. Longer missions planned for the near future will place new demands on both craft and crew. Shielding astronauts from radiation is the most serious problem—and also the one biomedical researchers know least about.

Astronaut Bob Stewart in the Manned Maneuvering Unit. The complex gear needed for the shortest venture outside the craft is proof that as visitors in space we may not be unwelcome, but we are "unexpected."

crews. The syndrome generally occurs only in the first few days of flight (although the Soviets recently reported that it also occurred late in a mission). "It's probably more of an annoyance" than a real concern for Mars, says Sulzman.

As troublesome as some of these adaptation problems are, for the most part they seem solvable: Soviet cosmonauts already spend a year in space without suffering serious consequences. Their answer is to spend two or more hours a day exercising in order to keep their bodies conditioned. (Yuri Romanenko, who spent 326 days in space in 1987, reportedly exercised up to four hours a day in the last stages of his flight.) Though the Soviets don't prevent deconditioning entirely, they at least minimize it, says Sulzman. NASA astronauts on long missions will most likely use exercise as a countermeasure as well.

And if simple countermeasures don't work, there's always the possibility of beating the harmful effects of zero-g by creating "artificial gravity" in a spinning spacecraft. One problem with that idea, says Holloway, is that we don't know the physiological effects of spinning people in space. "We would have to test these systems and try to learn about them before we launch somebody off on a potential three-year trip to Mars," he says.

Moreover, the craft has to be large in order to produce the required gravity, and shielding a long, narrow ship from radiation may present problems. What looks easy in the science-fiction films could end up being an engineer's nightmare.

Before making any decisions about the need for artificial gravity, NASA will want to test both people and hardware onboard space station Freedom. In fact, biomedical testing will be one of the station's greatest contributions to any program to send humans to the Moon and Mars.

Says Sulzman, "Many physiological systems are going to be altered by exposure to weightlessness. We need to have people in space for long periods to understand the consequences. The Soviets have shown that people can survive—but how functional are they? How long is the rehabilitation on Earth? How do you select a crew?"

One potential source of problems is that Mars crews will have to live in the self-contained and isolated environment of a spaceship. That brings up all sorts of issues: First, if any serious medical problems arise, the crew must be able to handle them on their own.

"On the space station, the goal is to provide a level of care the same as a small-town medical emergency room," says Holloway. A major emergency, such as an intestinal obstruction, could not be cared for; a bone fracture could.

A mission to Mars, where the crew could not return to Earth in an emergency, requires more sophisticated facilities. "We would need the ability to do major surgery," says Don Stewart, manager of NASA's aerospace medicine programs office. "We would have to have a restraint system for the surgeon, the patient and the instruments. We would need a system for collecting biological fluids—physical and airflow barriers so as not to contaminate the environment."

In addition to surgical equipment, there will probably also be monitoring instruments such as ECGs, x-ray machines and blood-sampling kits onboard, along with health maintenance equipment such as exercise bikes. But, Stewart admits, Mars voyagers will not have the same kind of medical care that would be available at a big-city hospital. For instance, they probably won't have a CAT scanner on board. "Things that are simple on Earth are complicated in space. Things that are complicated on Earth are very complicated in space," he says.

Then there's the question of how much medical know-how a Mars crew would need. Should there be a surgeon onboard? One way to get around it, says Holloway, would be through "tele-medicine"—sending vital signs and other medical data back to Earth, using onboard devices that would monitor physiological systems in much the same way that trauma units can now monitor patients remotely. But, he adds, with the delay in transmission time between Mars and Earth, there will still be a demand for onboard medical care. And once a problem is treated, the victim will probably need nursing. "With a four-person crew on the way to Mars, 24-hour nursing care becomes a huge draw-down," says Holloway.

Another consideration is the possibility that contaminants—biological or man-made—might run rampant in the airtight

environment of the spacecraft.

"Spacecraft potentially take 'sick-building syndrome' to an extreme," says Sulzman. "On Earth, you're not in your home or office 24 hours a day, seven days a week. On a spacecraft, there's unrelenting exposure. Things that you can withstand exposure to for brief periods can become much more of a problem in a chronic environment."

Could a virus or bacteria devastate a crew? "We've talked about that over the years," says Stewart. So far, he says, there's no indication that runaway viruses are likely. Studies show that in space, the immune system is probably mildly suppressed. There's also a concern about people sharing germs in space. However, he says, "the immune system has a lot of reserve. It takes a fairly catastrophic failure before it stops doing what it should do. We have no indication to believe that there would be any failure of the immune system [in space] to fight a virus."

So far, NASA has not had a problem with infectious diseases on either the shuttle or Skylab, where astronauts lived for as long as three months at a stretch. Among Soviet cosmonauts, anecdotal reports suggest that skin infections are not uncommon—occurring at the rate of about five percent on missions of more than 100 days. "I'm not sure that represents an excess of what you'd expect," says Stewart.

In a sealed spacecraft, there's also the possibility that man-made materials will give off potentially toxic gases. In fact, says Holloway, if a Mars crew member starts to perform poorly or suddenly develops psychotic symptoms, the first thing that comes to mind shouldn't be some obscure mental illness, but rather that the crew is being exposed to a toxin. The "off-gassing" of materials in zero-g and reac-

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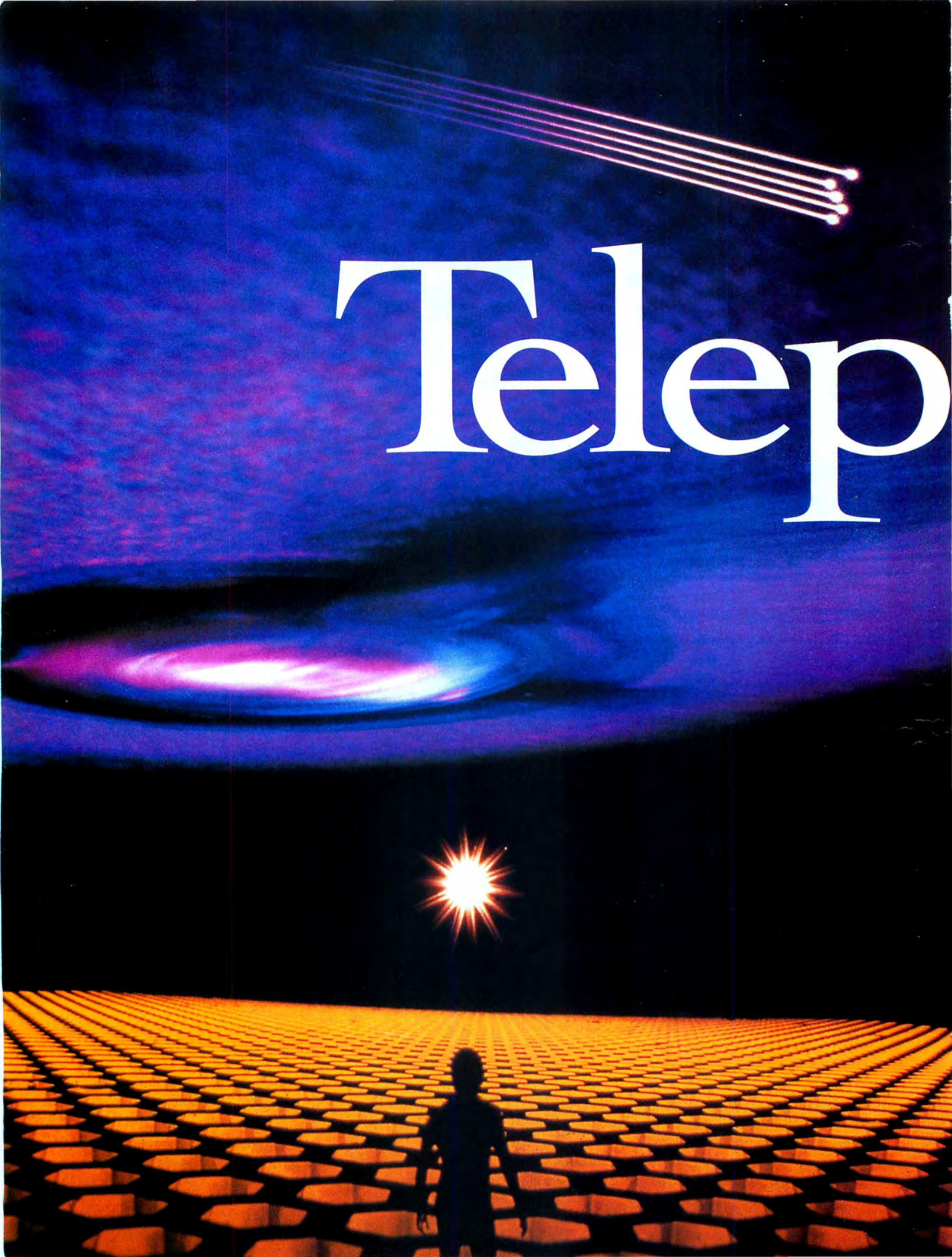
Telep

When minds merge with metal in the new world of

"virtual reality," seeing there will be like being there.

By Grant Fjermedal

resence

The best way to explore Mars may very well be on horseback, riding a trusty equine named Old Paint across the red deserts, over the highlands and through the box canyons.

Then again, an old Jaguar XKE sports car would be an excellent vehicle for touring the Martian landscape. In addition to being fast and beautiful, the XKE has windows that could be rolled up during dust storms.

In homage to the great astronomer and imagineer Percival Lowell, some will want to explore the planet in canal barges and riverboats. For the best aerial views of the great canyons, though, you may want to simply turn yourself into a flying dragon.

Space exploration is going to be fun. It's going to be safe, too. That is, unless you fall out of your armchair and bang your helmeted head against a table. And sad will be the explorer who breaks a helmet. For it will be the helmet, with its three-dimensional cameras wrapped around your eyes, that will transport you from Earth to other worlds.

A confluence of developments in robotics and computer science is enabling a new kind of merger between humans and machines. The result will be the new world of telerobotics, telepresence and, as the Japanese like to say, tele-*existence.*

We soon will be able to exist within robots, to be *present* within robots exploring other worlds. And with the ability to plug into computerized 3-D goggle systems, we'll be able to create new realms and new vehicles for exploring with the mind. Telepresence and tele-existence computer programs will make you certain you *are* on Mars. And with "virtual reality" systems that allow you to create your own personas and vehicles, you can do your exploration in style, perhaps as a lion surfing on dunes.

Scientists (and science-fiction writers) have long seen a need for robots in space. But earlier this year that perceived need took on a new urgency after a surprise report from NASA found that maintenance time for the $30 billion Freedom space station may have been grossly underestimated.

The report, by a special team at NASA's Johnson Space Center in Houston, upped the estimate of required space-walking maintenance time from 130 hours a year to 2,200 hours. The team analyzed all the components along the outside of the proposed station, considered the environmental stresses these materials would be exposed to, and determined that NASA could expect one outside equipment failure a day. While some call the numbers too pessimistic, space agency officials admit they have to find a way to cut down on the number of spacewalks.

At first thought, space can seem like a gentle environment: all that soft blackness with moons and planets and stars just floating there in all that nothingness. But temperatures in space can soar to 400 degrees Fahrenheit in sunlight, minus 250 degrees in shadow. There is the ever-present flow of radiation, and the bombardment from micrometeoroids and billions of pieces of space junk that range in size from flecks of paint to wrenches and chunks of metal.

Even if the 2,200 hours of extravehicu-

JEFF ZARUBA/THE STOCK MARKET

lar maintenance could be halved, science would be at a standstill onboard Freedom, as the astronauts would be reduced to high-flying repairmen. What's more, they would be exposed to the brutal conditions of open space for long periods.

NASA, which has sometimes been criticized for its bias favoring humans, is suddenly paying serious attention to the case for robotics.

At first, robots onboard the space station will require a lot of human attention as they will lack the artificial intelligence required to work on their own. A human will be required to operate the robot, but the benefit will come from the astronaut's ability to stay inside the space station and let the robot experience the difficulties and hazards of a spacewalk.

Through visual and tactile interfaces, the human mind will be able to merge with the robot's metal. Outside the station will be the robot, with two video cameras for a head. Inside will be an astronaut wearing headgear that cuts out all vision save for the three-dimensional images being transmitted live through miniature televisions set into the wearer's goggles. The astronaut will feel as if he or she is outside, dwelling inside the head of the robot.

When the head of the astronaut turns, the head of the robot turns. The astronaut's hands will be inside tight-fitting gloves with fiber-optic sensors that transmit every move to the hands of the robot.

In this way the astronaut can pull himself—that is, his robotic self—along the spacecraft, find the panel that needs to be serviced, open it up and swap out old parts for new.

To free the astronaut from even this chore, new jobs might arise on Earth in which people drive to work and spend their days plugged into the hands and eyes of a space station robot. VPL Research of Redwood City, California already makes commercial products meeting both needs: stereo-vision goggles called the EyePhone, and a telerobotic device for the hand called the DataGlove.

The major difference between astronauts and the Earthbound operators of orbiting robots would be the time lag between sending a signal from Earth and having it executed by the robot. Ideally the message would travel at 186,282

VPL RESEARCH

VPL RESEARCH

The tools of "virtual reality": The DataSuit, DataGloves and EyePhone made by VPL Research, Inc. in California (opposite) let you "fly" through a world that exists only in a computer and in your mind. Fiber-optic sensors in the glove (above) link the real hand with its computer-generated image.

miles a second, but unless the station were in high geosynchronous orbit (Freedom won't be), a direct uplink would require an expanded network of tracking stations. Even then, the instructions to the robot would likely be channeled through NASA's Marshall Space Flight Center in Alabama or some other ground center for command checking.

"It's a huge problem called transaction management," explained Duncan Atchison, a Lockheed senior engineer supporting the space life sciences. "There are a number of people on the space station team looking at that. How much freedom is there going to be to do telerobotic work from the ground? NASA is very concerned with safety. We can't have just anyone on the ground pumping up commands. Suppose someone was operating a telescope or other large instrument that was mounted as an attached payload, and when he moved the object it hit someone in the back of the head."

Another example, says Atchison, is that you wouldn't want a ground-based operator to start a centrifuge spinning if scientists on Freedom were in the middle of growing a delicate crystal. "One guy's activity can mess up someone else's science," he says. Preventing conflicts like these is the purpose of Marshall's inte-

grated science operations center.

The same technology that links human teleoperators on the ground to robots onboard Freedom will naturally lead to human telepresence on other planets. But before sending robots off to the Moon or Mars, NASA may practice teleoperations in Antarctica, says Geoffrey Briggs, who heads the agency's planetary exploration program. Right now, scientists who explore Antarctic lakes looking for clues as to whether life might have developed in Mars' watery past are restricted to diving during the southern summer. Briggs is looking at the possibility of having the same scientists explore the same lakes without ever leaving San Francisco, using submersible telerobots. Not only would that open up a new winter diving season in Antarctica, he says, it would serve as good practice for Mars.

As the hardware and software of robotic brains get better, there should be less need for direct human interfacing with robots doing routine chores. At some point a space station robot should be able to respond to requests like: "Please go out to the number six bay and test unit number two. If it doesn't test out, all of us here on the station would think highly of you if you were to swap it out. Thanks."

Armed with a pattern-recognition visual program, with a three-dimensional blueprint of the entire space station and all components, and with a branching 'if-then, if-then' knowledge of its domain of responsibility, a robot should be able to work well on its own. It would only need to call for help when it encountered a situation that didn't match its criteria for action.

A robot in need of human assistance might say something like: "I know you guys are busy watching football, and I say that with the utmost admiration, but I could use a second opinion if you could do me the honor of peering through my eyes for a moment."

Such autonomy will be increasingly required as we send the robots further into space. Consider Mars, which seems such an irresistible planet for "terraforming" into a more Earthlike world. Depending upon its orbital position, instructions could take from 20 to 40 minutes to reach a robot building condos on Mars, with another 20 to 40 minutes required for the Earthbound foreman to see whether the robot succeeded in attaching the solar panel, or whether it broke another one. We need robots that, like good workers, can follow general instructions and improvise along the way as needed.

One day in Japan I had the pleasure of visiting the laboratory of one of the world's foremost researchers in robotic telepresence. Susumi Tachi, senior research scientist at the Robotics Department of the Mechanical Engineering Laboratory at Tsukuba, has taken the science of telepresence to the ragged leading edge of tele-*existence*.

In some ways the visit changed my life, because I had such an intense out-of-body experience there. Forget astral projection and hocus-pocus spiritualism. Susumu Tachi can take you out of your body, and in so doing shake your concepts of the meaning of life and death. The experience also will leave you longing for the chance to have your senses, your *self*, transmitted into a host robotic body on the Moon, or on the space station, or into anything else orbiting our great blue marble of a planet.

VPL RESEARCH

Tachi's vision system truly gives you the feeling that you are *inside* the robot, looking at the world from within its body, not your own. This is possible because the operator isn't just looking at a television monitor; his head is encased in a black velvet-lined box. Within this box are two television receivers, one for each eye. The receivers are gauged so that the image reflected against the retina of each eye is exactly the same as if you were looking at the world unaided. Further, every movement of your head is duplicated on the robot, where two precisely placed video cameras transmit a human range of what is seen.

The effect is startling. When I went into the laboratory and strapped my head inside the black velvet box, it was as if I were seeing with my own eyes. The depth and scope of human vision was so completely reproduced, and the color so clear, it was unsettling at first, then a wild visual delight. Whenever I turned my head or looked up or down, the image transmitted to the retinas of my eyes was completely faithful to what I would see unaided. I studied the computer panels, the work tables of the laboratory, the people. Then I came upon a life-size mannequin wearing a pair of sunglasses. How odd that was. It was as if I were one mannequin looking at another, fully expecting that she, behind those shades, would be able to look back.

Someone in the laboratory went over to the robot-mounted cameras and swung them around so that they focused on me. The walls spun during the maneuver, and then when the motion stopped and I was looking at myself, the out-of-body experience began. It was as if I were standing a few feet away *in another body* looking at myself. I moved my head to look up and down and even to look away. And when I looked away from that person who was me, it was as if that body were just another passerby.

But I couldn't ignore that guy for long, and I turned my head back to look again at this person who was standing across from me with his head strapped into a black velvet box. The scientists in the laboratory laughed. They knew what was going through my head, for it had also gone through theirs during their own encounters with their out-of-body selves. "Are you here?" Tachi laughed. "Or are you there? Where is the body?"

COURTESY DR. S. TACHI/MECHANICAL ENGINEERING LABORATORY

The "tele-existence" system being developed at Japan's Mechanical Engineering Laboratory could allow us to explore Venus or Mars from within the "body" of a robot.

And this is why I can say that very soon, we will *all* be able to go into space.

Tachi could put you into low Earth orbit, or onto the surface of Venus, where non-robotic bodies could never survive. He could soothe the boredom of a long flight to Mars by letting astronauts go hang gliding in Hawaii without ever leaving their sterile metal spacecraft.

But Jaron Lanier, founder and chief executive of VPL Research Inc., can put you inside a computer, inside a human cell, or have you sitting next to Alice at the Mad Hatter's tea party.

The virtual-reality hackers like Lanier also use televised goggles that completely cover your eyes, but instead of feeding in live video from a slave robot, they allow you to dive inside a computer-generated world. When equipped with something like VPL's DataGlove, you can pick up objects that exist only within the program and your mind.

The brain has a need to make sense out of environments, to create order from chaos and fill in the gaps. What this means is that even crudely rendered three-dimensional worlds become absolutely real and believable domains when viewed through stereo goggles.

Down this path lies possible addiction, and incredible sojourns into wonderlands that not even Lewis Carroll could have imagined or comprehended. And NASA is helping to get us there. In addition to offering new means for wild exploration, virtual reality systems provide, for the more sober-minded, a new level of human interfacing with computerized data.

"The physical world is the environment we are most familiar with," said Steve Ellis, research scientist and head of the Spatial Perception and Advanced Displays Laboratory at the NASA Ames Research Center in Mountain View, California. "But because of various NASA projects there is an interest in interacting with the remote world.

"The world might be remote in the sense that it's on the surface of a planet like Mars, or on the Moon," Ellis said. "But it might also be remote in the sense that it's synthetic and generated inside of a computer. What we then need is some kind of interaction metaphor, so that the expectations and habits that we've developed through our interaction with the real world are useful tools within remote worlds."

That means having the objects within your computerized world obey the laws of physics, although when it's convenient, you can give yourself super powers like x-ray vision and the ability to leap across Martian canyons with the wiggle of a finger.

A scientist who wanted to find mineral deposits on Mars could goggle into the computerized world of mountainous data returned from planetary probes and request that all areas of possible copper deposits jump up and down or change colors.

It will be a new kind of user-friendly exploration. The goal, in Ellis' words, is to "synthesize worlds that are understandable and useful."

Ellis speaks of "virtual planetary exploration," explaining that as planetary probes relay huge amounts of information for incorporation into planetary models, "one way to visualize the model will be to create the planetary surface with a computer and view it with the illusion that you are on the planetary surface."

You needn't be alone in this computerized world, according to Ann Laskko-Harvill, director of product design at VPL. One of the more intriguing aspects of this intriguing field is that two or more people could meet in the same computer-generated world.

From a scientific standpoint it means a Russian geologist could join colleagues from the United States or France in the same computer model. Equipped with data gloves, they could shake hands, pass samples back and forth and talk about what they were seeing.

And because nothing in this world would really be real, each scientist could come in the persona of their favorite cartoon character or dinosaur. And like Peter Pan they could join hands and fly away.

Scale isn't an issue either. If an electrical problem developed within the space station, five Earthbound electrical engineers could join the astronauts in a virtual reality of the electrical system. Like tiny mice they could roam up and down the cables leading into electrical panels and not worry about getting a shock.

At one point NASA's Steve Ellis talked about the two dimensions of a spreadsheet not being enough, and of how it would be nice to dive into a computerized VisiCalc of six or eight dimensions.

Whoa! NASA talking about *cyberspace*!

William Gibson is the intuitive genius who wrote the award-winning science fiction novel *Neuromancer*. Published in the appropriate year of 1984, Gibson's book introduced the world to the word "cyberspace" and created mind-soaring images of things that appear to be coming true.

If you want to know what it's going to feel like plugging your brain directly into a cyberspace navigation deck to explore the world's computer systems from the

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Driving FTS: Turn On, Strap In, Step Out

The earliest telerobot planned for space station Freedom, the so-called Flight Telerobotic Servicer (FTS), will be used for routine work outside the station. We asked Curt Newport, who pilots deep-ocean telerobots and serves as an advisor to NASA's space station project, to describe how it will be to "drive" the two-armed wonder known as FTS.

Freedom is flying, gliding across the sky at better than 17,000 miles per hour, swiveling its solar arrays, pumping thermal fluids, and occasionally firing a thruster to keep it on track. It all works. But suddenly, there's a failure in one of the systems. It's not life-threatening, just serious enough to drag you out of your zero-g sleeping cocoon at 0200 hours Houston time and make you and your teleoperated robot go to work.

You're stuck up inside a windowed cupola mounted on top of one of the station's resource "nodes," gently drifting around in your awkward-looking body restraint. You aren't physically tired, but your brain is a bit foggy. It's dark outside, the only illumination coming from the rows of lights mounted on the station's girder-like truss.

A few small droplets of condensation on the inside of the window remind you of the intense cold outside. In spite of the racket from the fans and pumps

of the environmental control system, occasionally you hear, or actually feel, a low rumble run through the station as you watch the Canadian-built Mobile Servicing Center (MSC) slowly trudge along the forward face of Freedom's truss.

Your job is to change out a "control moment gyro" mounted to a pallet on top of the starboard truss, which supplies essential attitude control to the station. The backups have automatically taken over, so there's no danger. But still, it has to be replaced, and Mission Control wants it fixed *now.*

You've already used the station's long, spindly remote manipulator arm to pluck FTS from its "doghouse." You've fastened the robot to a grapple fixture on the MSC and finished all the power-up checks. Now you're just waiting for everything to get into position.

The computer terminal in front of you burps, then spits out a message, "CMD TRSSTRC 0002: MSC in position at SB-2, ready to deploy FTS...Proceed?"

Somewhat chagrined at your lack of participation so far, you hit the return key. The computer blinks a moment, then writes, "Deploying FTS."

Outside, visible to you only on a pair of high-resolution video monitors above the keyboard, Freedom's 50-foot arm slowly unfolds itself like a gigantic insect, attaches itself to FTS, pulls it clear of the MSC and positions it near the pallet

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HEAVENS' GATE

An expanded space station may be the harbor from which explorers depart for the Moon and Mars.

The year: 2015. The press and the rest of the world have already seen the four international crew members leave Earth for the aging ramparts of space station Freedom. Now, after several days of additional preparation, they've taken their places in the crew module of their interplanetary vessel. There is a drama in the countdown that the simple recitation of numbers belies. Slowly, in the utter silence of space, the huge arm of the remote manipulator disengages their titanic space ship from Freedom's assembly hangar and sets it adrift. For a moment, there's time for each crew member to wonder how he or she will handle the longest journey any human has ever made. ■ From where they sit, cradled amid tanks, cargo and the leviathan aerobrakes that will bring them skidding to a fiery halt on the edge of a distant atmosphere, they cannot see their destination; but they've gazed upon it often from the portholes of the space station—a tiny, unwinking, red beacon in an infinite sea of stars: Mars, more than 35 million miles away. ■ With the ship now clear of the station, the pilot uses tiny doses of rocket fuel to move the craft into position for takeoff. Then, with Earth spinning below, Freedom a safe distance behind, and the Moon, bright and full, bearing lunatic witness, the ship's enormous engines fire. Like a single Roman candle in the night, the 730-ton ship roars out of Earth orbit, and the first humans to visit another world are on their way.

By Chip Walter

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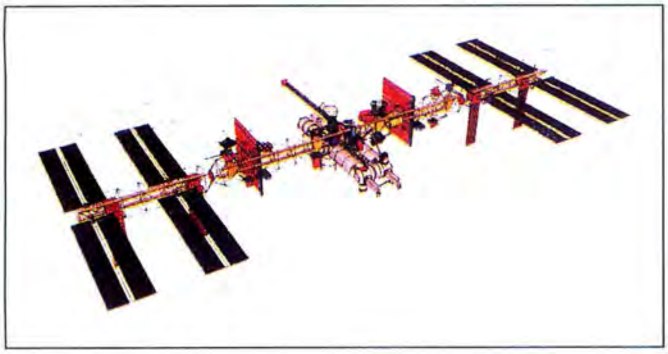

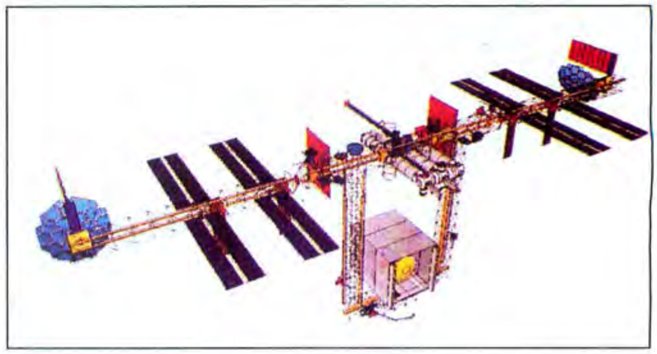

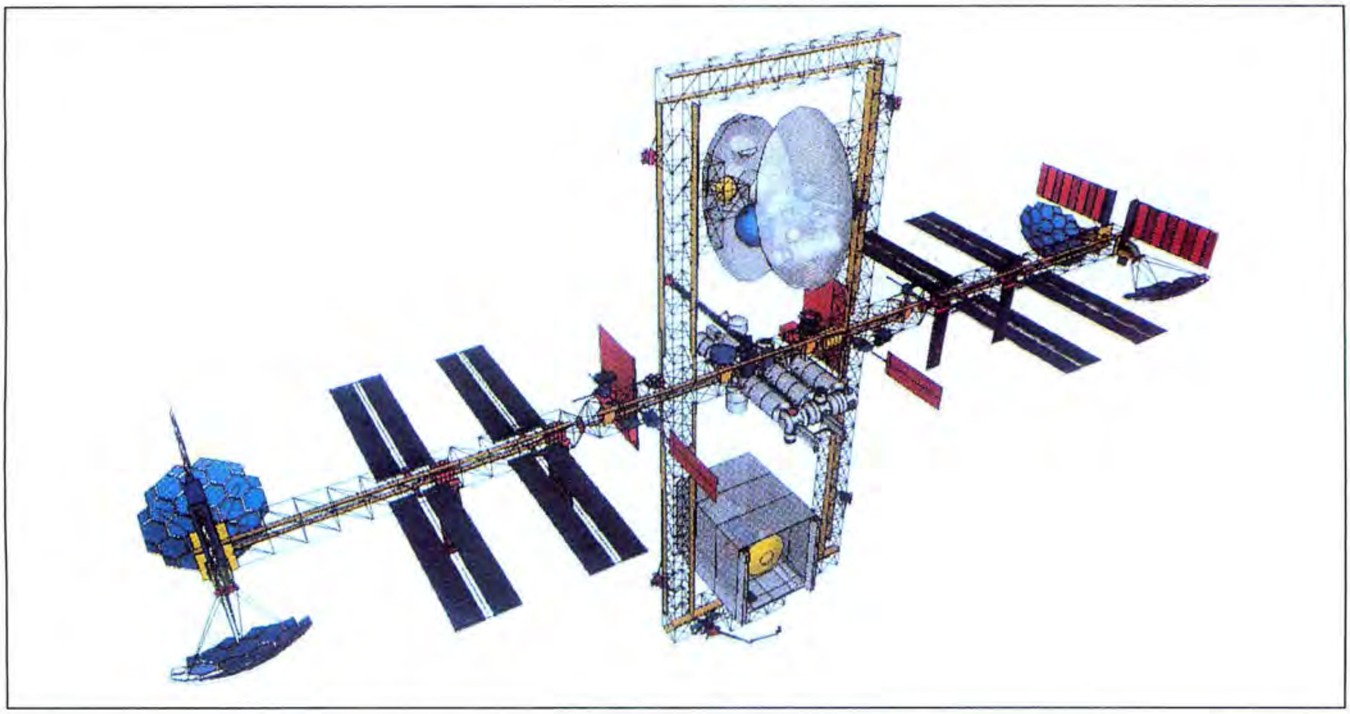

If a spaceship ever actually begins this journey, it will mark the culmination of a dream held by many of rocketry's great pioneers. Hermann Oberth, Robert Goddard and, of course, Wernher von Braun all wondered about such a voyage.

Von Braun was the most recent of the dreamers. He wrote in great detail about the human exploration of Mars, and he always stated his case boldly and dramatically. He was the Cecil B. De Mille of scientists, a Wagner among engineers, and as early as the 1940s he envisioned launching a flotilla of 10 rockets to the Red Planet "manned by not less than 70 men." (His vision failed to predict the likes of Sally Ride.)

The centerpiece of this expedition was to be a wheel-shaped space station orbiting Earth. Here he foresaw an army of workers assembling the spaceport that would launch the first humans to Mars.

Early in the next century, Freedom will grow from a single-keel orbiting laboratory (top left) to a busy Moon-and Mars-port. A bay for lunar vehicles (top right) will be added first.
By the time the Mars vehicle with its large, shell-like aerobrakes (above) arrives, "solar dynamic" dishes at each end of the station will be providing additional power.

His plans for a flotilla and 70 men fell a little wide of the mark, but von Braun hit the nail on the head when he foresaw the need for a space station that would act as a harbor for departing voyagers.

Forty years after von Braun's ruminations, it appears that some version of his dream may yet come to be. Until recently the United States seemed plagued by an epidemic of space exploration options. In the wake of Challenger, reports stacked up on desks in Washington while scientists and engineers and politicians clamored for everything from a flag-planting mission to Mars to a relatively staid (unless you're an astronomer) Antarctic-like science station on the Moon.

Then last July President Bush finally laid out the administration's plans for America's future in space: take the beast by the horns, first by returning to the Moon ("this time, back to stay"), then by mounting a human mission to Mars and establishing a permanent colony there. The speech didn't take long, but its implications are both staggering and heartening to anyone interested in the long-term future of space station Freedom.

Prior to this announcement, Freedom's fate beyond the completion of its first phase as an orbiting laboratory had remained lodged firmly in neutral. But a plan call-

The Best-Laid Plans

Following President Bush's call last summer for bases on the Moon and Mars, NASA engineers quickly developed five possible plans for achieving those goals. These "reference approaches" range from the simple to the complex. Predictably, the plan with the most stretched-out timetable has since emerged as the favorite, and is the basis for all the dates used here. But there are other proposed scenarios, both within the space agency and outside it.

Anyone who follows the fortunes of NASA knows that politics, economics and the unpredictability of high technology make only one thing certain in the space business: *nothing* is for sure. With that in mind (and short of the entire project being scuttled) here are some of the more important changes that could affect whether, when and how Freedom becomes a space port.

IF	THEN
Political support and funds are lacking...	Keep moving all the dates back, and back, and...
The Soviet Union should join the United States' other international partners in Freedom's expansion...	Its most impressive contribution could be Energia—the heavy launch vehicle that the United States so sorely lacks. Energia is a real rocket, not a CAD/CAM engineer's dream, and it can already tote 220,000 pounds into low Earth orbit. The Mir space station could also become a welcome addition to the effort.
NASA engineers cannot prove that their new design will avoid disrupting Freedom's sensitive microgravity experiments (which are very important to certain U.S. interests as well as to Japan and Europe)...	A separate unmanned station could be constructed exclusively for assembling and servicing lunar and Mars-bound spacecraft. This would blow a Jupiter-sized hole in NASA's schedule for establishing bases on the Moon and Mars.
The deleterious medical effects of weightlessness cannot be managed, at least in the short term...	Engineers may have to consider a Mars vehicle that creates its own artificial gravity, perhaps with a tethered, rotating habitation module.
Public sentiment changes *and* NASA can successfully argue the case...	The first ships bound for Mars could be nuclear-powered. The technology exists now, and nuclear ships would reach Mars in close to half the time (while solving some tough logistical problems—supplies and the effects of weightlessness among them).
Fast nuclear-powered ships are out, and "closed environmental systems" that recycle water and air and allow the cultivation of edible crops in weightlessness aren't developed on Freedom beforehand...	The space program must resign itself to 300-day trips to Mars—and to the fact that inhabited bases on the Moon and the Red Planet may simply be impossible in the immediate future. Napoleon thought his supply line from France to the Russian front was long. Try the 35 million miles between Earth and Mars.
Congress becomes concerned about the danger to astronauts working in space...	Freedom's expansion could be considerably delayed as a protective hangar is constructed during the expansion's first phase (rather than the second), *and* as engineers work to develop more sophisticated robots that can perform many of the chores now considered too complex for machines to accomplish.

ing for the colonization of the Moon and Mars created an instant need for an orbiting port—a way station and launch point for the spacecraft that will supply and people those distant settlements.

If the president's goals are to be transformed into realities, NASA believes that Freedom, like von Braun's station, will have to become the hub of the new Space Exploration Initiative (SEI to acronym-mongers). But before it ever reaches its final configuration, engineers will face a morass of chilling, and exciting, challenges; changes that will make the construction of the original station—no mean accomplishment in itself—seem like the smallest of engineering potatoes.

Before a Mars-bound craft departs Earth orbit, Freedom will have to undergo a four-phase conversion that will see it transform from a relatively simple orbiting laboratory to a full-blown spaceport. True, it will never become the gleaming, spinning wheel of Stanley Kubrick's *2001: A Space Odyssey*. But it will change enormously, roughly doubling in size as it's outfitted to construct, repair and launch the first reusable interplanetary spacecraft: ships like no others before them, with aerobrakes the size of skating rinks, elaborate living systems and house-sized fuel and cargo holds.

To accomplish this, 12 permanent crew members and a growing rookery of robots will labor high above Earth for more than a decade. Freedom will become the testing ground for tackling the many problems of interplanetary travel and colonization. Crew members on the station will be as scrutinized as a warren of white laboratory rats, to see how they handle the psychological and medical stresses of life in space. Technicians will try out new methods for recycling water, air and food. Samples of Martian rock and dirt, gathered by roving robots, will be returned to the station for study.

How will all this take place? Given the green light from the White House (but

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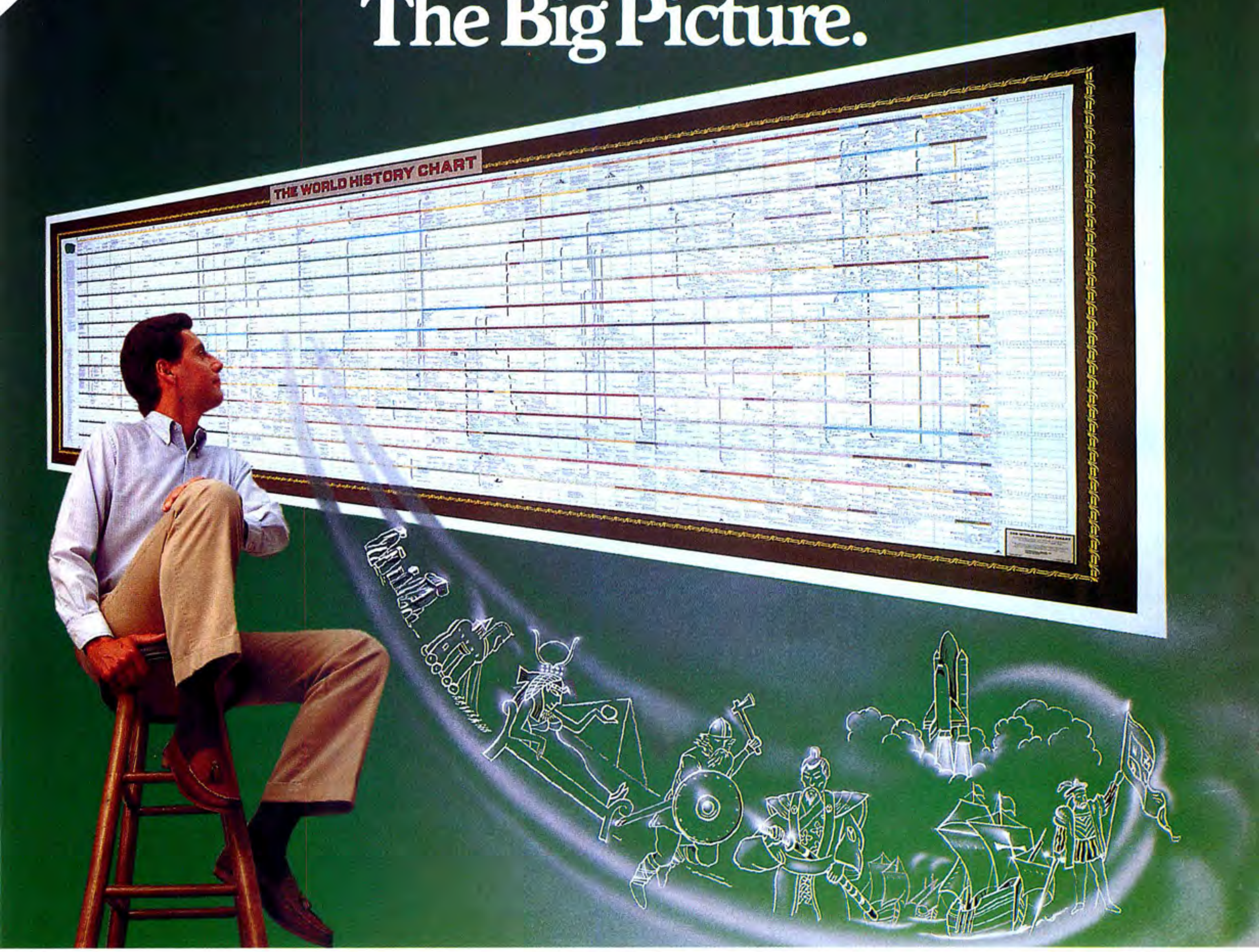
new fifth edition

The History Of The World Comes Alive When You See The Big Picture.



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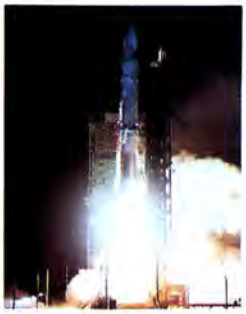
FF-3

10,000 Toyotas



equal just one rocket launch in the global balance of trade.

But can U.S. companies compete in the new commercial space race?

In the tense, multibillion-dollar war against the trade deficit, American rocket launchers suddenly find themselves on the front lines. The venerable workhorses of NASA's past—Delta, Atlas and Titan—are now cast in a new, unfamiliar role as their owners struggle to make a profit launching satellites for paying customers.

Florida congressman Bill Nelson summed up their importance to the American economy last November when he said, "The sale of one commercial launch by a U.S. company is the equivalent of the import of 10,000 Toyotas." But unless U.S. policymakers want to see American-made launchers go the way of the Buick, they'll need to address a host of trade, technology and competitiveness issues, and they'll need to do it soon.

The Defense Department and NASA, of course, can always be counted on to buy Buicks—that is, U.S. scientific, military and weather satellites will always be launched on U.S. rockets. Other spacefaring countries have the same kind of captive market when it comes to launching their own national payloads.

But the Atlas and other vehicles derived from Cold War-era missiles have now entered an international "gold war." Commerce Deputy Secretary Thomas Murrin, in remarks to the spring meeting of the U.S. Space Foundation, said, "In 1990, just the second year of operations for [U.S.] commercial launch services, we project revenues to exceed $600 million." That's just for the launches. It doesn't include the satellites themselves, which represent another $2.5 billion in business.

As Murrin puts it, "In the 1990s, we are in a new space race, this time for commercial superiority in space. We are joined by tough competitors—the Soviets, Europeans, Japanese, Chinese, and prospectively the Australians." How the United States deals with competition on the launch pad is thus becoming a measure of its economic competitiveness as a whole.

By Melinda Gipson

World Spaceports

A list of 25 existing and planned launch sites, numbered from left to right:

1. **Palima Point/Kahili Point, Hawaii:** Two possible locations for a proposed $400 million commercial launch complex on the large island 60 miles southwest of Hilo. If financing comes through, ground breaking for this four-pad, major facility is scheduled for 1992.

2. **Vandenberg Air Force Base, California:** The Western Space and Missile Center includes pads for the Titan 4, Atlas and Scout rockets. Vandenberg is the principal U.S. site for reaching polar orbits.

3. **White Sands Missile Range, New Mexico:** Suborbital launch facility operated by the U.S. Army. Supports flight testing for the Strategic Defense Initiative and launches for NASA's Commercial Centers for the Development of Space.

4. **Cape San Blas, Florida:** Plans are underway to reopen this suborbital site maintained by the Air Force in northwestern Florida's Gulf County.

5. **Cape Canaveral and Kennedy Space Center, Florida:** Cape Canaveral, operated by the Air Force, has five pads available for large commercial launchers: two Delta, two Atlas and one Titan. Another pad is dedicated to the Titan 4 rocket used by the Defense Department. Canaveral is the site of most domestic U.S. commercial launches to date. NASA's space shuttle is launched from the Kennedy Space Center.

6. **Wallops Island, Virginia:** Sounding rocket facility operated by NASA's Goddard Space Flight Center. Considered a possible site for future suborbital commercial launches.

7. **Kourou, French Guiana:** Launch site for the European Ariane rocket.

8. **Alcantara, Brazil:** an expanding facility controlled by Brazil's Ministry of Aeronautics. The facility may eventually launch China's Long March and the Soviet Proton—both countries have shown interest in using the site.

9. **Barreira de Inferno, Brazil:** Smaller sounding rocket facility, located near the city of Natal.

10. **Andoya, Norway:** Ten remote launch pads for sounding rockets.

11. **Esrange, Sweden:** Six permanent sounding rocket facilities operated by the Swedish Space Corporation (SSC).

12. **Plesetsk, USSR:** The world's northernmost and busiest major launch facility—1,111 launches between 1957 and 1985, most of them for the Soviet military.

13. **Kapustin Yar, USSR:** A site for small and suborbital launches, located north of the Caspian Sea.

14. **Baikonur, USSR:** Also known as Tyuratam. Located in central Asia near the city of Leninsk, this is the launch site for all Soviet manned flights.

15. **Palmachim AFB, Israel:** Site of two recent Ofek satellite launches. Located south of Tel Aviv.

16. **San Marco Island, Kenya:** Owned and operated by the Italian government, located three miles off Kenya's coast. Pads for the small Scout launcher were reactivated in 1988 for the first time in 12 years.

17. **Thumba, India:** Equatorial site for sounding rockets.

18. **Sriharikota Island, India:** Orbital launch site operated by the Indian space organization ISRO.

19. **Balasore, India:** Sounding rocket facility.

20. **Jinquan, PRC:** A Chinese facility for smaller capacity rockets. Located in Kansu province, 1,000 miles west of Beijing.

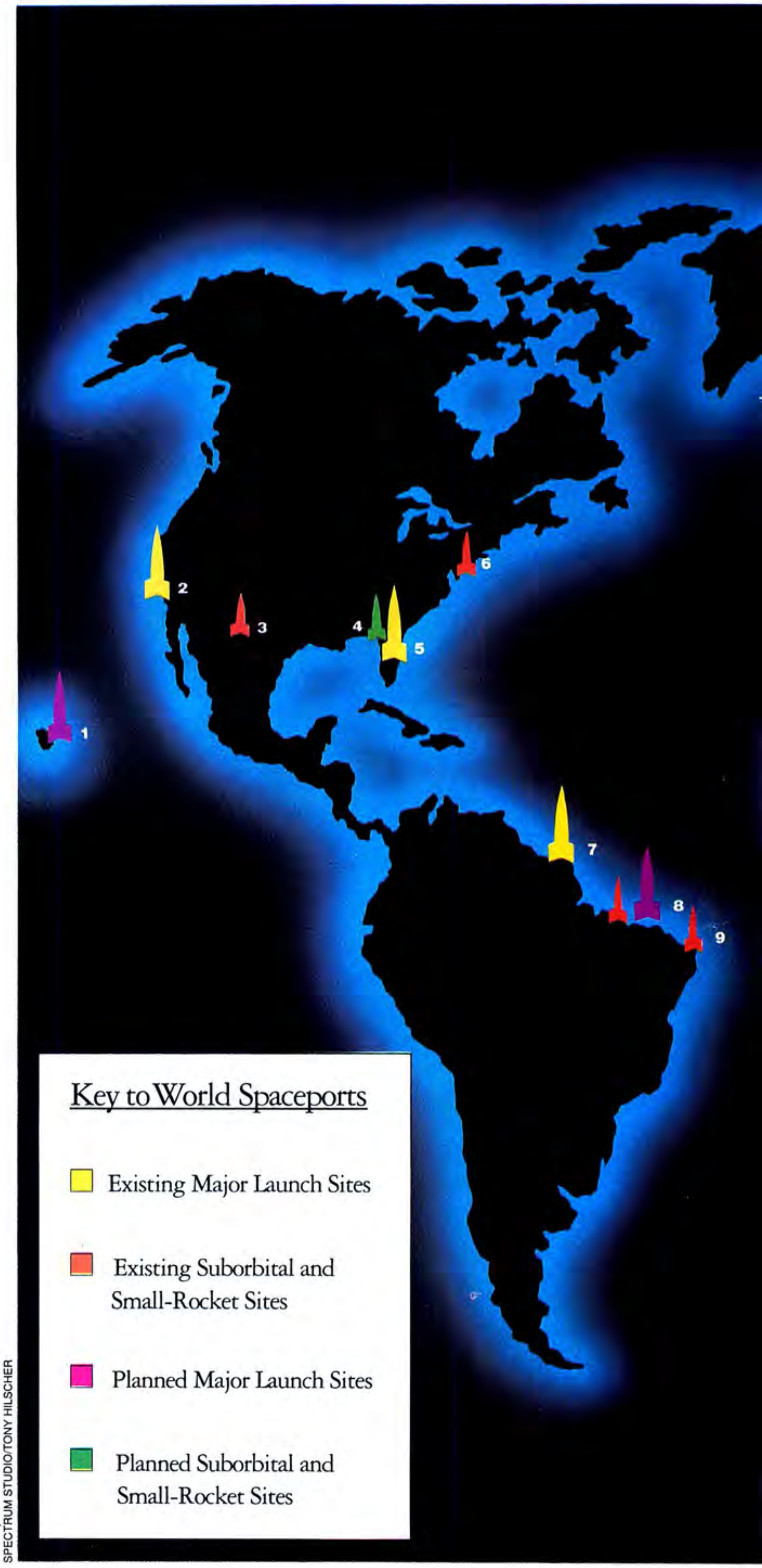
21. **Xichang, PRC:** China's major facility for launching larger versions of the Long March rocket. Located in Sichuan province.

22. **Kagoshima, Japan:** Sounding rocket facility.

23. **Tanegashima, Japan:** Major facility for the H-1 rocket operated by Japan's NASDA space agency.

24. **Woomera, Australia:** Sounding rocket facility reopened in 1987.

25. **Cape York, Australia:** A major commercial facility is proposed for a 150,000-acre site in northern Queensland by the Cape York Space Agency, a private Australian company. The Soviet Zenit would be the facility's main launch vehicle.



SPECTRUM STUDIO/TONY HILSCHER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Among the "Big Three" American rocket companies, the General Dynamics Atlas has so far been the clear winner over the McDonnell Douglas Delta or the Martin Marietta Titan in signing commercial contracts. The latter suffered an embarrassing setback in mid-March, when a wiring error on a Titan 3 rocket stranded an Intelsat satellite in the wrong orbit. With Martin's fortunes declining in the commercial satellite market, the only real prospects for its large vehicles may be with government contracts.

Meanwhile, U.S. launchers are feeling the hot breath of foreign rocket trails on their necks, not just from their traditional rivals, but from "non-market" economies like China and the Soviet Union.

In early April, China launched its first Western-made satellite on a Long March rocket, for which it charged the Asiasat consortium $30 million—as much as 40 percent less than the cost of a U.S. ride.

"Not fair!" shouted American launchers, who alleged that the price charged to Asiasat wasn't based on actual cost. In fact, Chinese marketers admit, it was deliberately set lower than whatever Western launchers were charging. "And it will always be less than ours, so long as our workers live in San Diego suburbs and theirs in government-supported housing," noted a General Dynamics official.

Why let such a competitor into the U.S. market at all?

The answer lies in President Bush's close kinship with China, which dates back to his years as U.S. ambassador to Beijing. A White House decision to allow China to launch American-made satellites meant that U.S. officials had to struggle to craft an agreement that would at least "level the playing field" for U.S. commercial launchers.

The 1988 agreement limited the number of Western-made satellites the Chinese could launch to nine over six years (the U.S. government controls the export of American-built satellites as a means of preventing "technology transfer"). A second stipulation was that Long March buyers be charged rates "on par" with Western rockets.

"It wasn't the greatest deal in the world," says the Department of Transportation's rocket counsel Gerald Musarra, "But we did the best we could, considering the decision to deal had already been made."

Then the U.S. Congress got involved, and export papers for the Asiasat satellite were suspended after the political unrest and riots that climaxed in Tiananmen Square. Legislative action forced Bush to personally certify that it was in the national interest to let the satellite be shipped—which he did, despite congressional outrage.

Now America's deal with the Chinese faces an even more severe test. China recently won a contract to launch the Arab consortium's next satellite, Arabsat-C, after bidding approximately half what Western rockets would charge, and throwing in the cost of modifying the satellite for the Long March. Stephanie Lee-Miller, the top commercial launch industry advocate at the U.S. Department of Transportation, joined others in saying the deal constitutes a breach of China's agreement. A series of talks were scheduled for June to bring China to the table and force a change in market practices. But it appears the fox may be in the chicken coop to stay.

Arianespace, the European rocket consortium and chief competitor to American launchers, is challenging the Chinese more assertively. Because Arabsat-C is being built by a French-led consortium, Arianespace filed suit against the government to block the satellite's export from France. At the same time, the company is putting pressure on U.S. policymakers to take a stand. Doug Heydon, Arianespace's U.S. director, says, "We're all anxious to see how the United States reacts to this blatant dumping."

While American launchers may agree, it's tough to swallow the idea of Ariane as an ally. Clearly the cock of the walk, Arianespace now garners fully half the worldwide commercial satellite launch market. Offering rides for around $95 million per dual launch, the company boasts a backlog of more than 34 satellite contracts.

Some 15 of those customers are Europeans whose countries have a large investment in Ariane's success. But eight others are U.S. contracts snatched from the backyard of American launchers. Of the 20 or so launch contracts signed last year, about half went to Ariane, the other half to General Dynamics' Atlas. Only one was added to Delta's list.

Even that would be tolerable, say U.S. companies, if not for the threat from Ariane 5, which is scheduled to make its first flight in 1995. Europe's next-generation launch vehicle is being funded (at a cost of more than $4.5 billion) by the governments that contribute to the European Space Agency. Another $1.5 billion will be spent on improvements to Ariane's launch pads in French Guiana. The combined result will be another 40 percent reduction in launch costs.

At the same time, U.S. launchers are forced to contend with overtaxed Air Force launch pads at Cape Canaveral, where tracking services can take two days to be reconfigured after a government launch. That two-day wait may have cost Hughes—the satellite provider for a recent Delta launch—$2 million in performance bonuses, according to Steve Dorfman, corporate vice president of Hughes' space and communications group.

As the head of a committee to advise Lee-Miller on launch policy, Dorfman looked at the impact that commercial spaceports such as those proposed for Florida and Hawaii (see chart, page 38) might have on domestic launchers. He came away unimpressed. "It's questionable in my mind whether any commercial spaceports will get the private investment they need to get off the ground," he said.

The exception, says Dorfman, might be the launch facility the Australians are building at Cape York to begin operation in 1995. Although the Cape York Spaceport Authority, a commercial group set up to build the launch pad in northern Queensland, has no government funding, it does have a launch vehicle in mind. Of course, it happens to be Russian.

The Zenit is a marvel of technology. The Russian launcher has roughly the same capacity as a Titan, which can loft 31,600 pounds to low Earth orbit or a giant Intelsat 6 satellite to high geostationary orbit. The Zenit can accomplish all that at perhaps a quarter of the cost of a Titan, while spending less than a day on the launch pad.

Australians say that fears of cheap Soviet rockets flooding the world launch market are unfounded. True, the Cape York authority has negotiated exclusive use of the vehicle outside the Soviet Union, and, yes, the Zenit itself costs only $28 million to $30 million to purchase. But the only

continued on page 52

Astronauts, Cosmonauts,

International astronauts used to be guest stars. Soon they'll have their own show.

By Maura J. Mackowski

Remember when you were a kid, looking up at the Moon and stars and thinking: I can go there too. If I eat my spinach, clean my room, learn my long division and say the pledge of allegiance every day, I can grow up to be an astronaut.

Well, maybe if you were an American kid. But a lot of others in Switzerland, Japan, Indonesia, France—in fact, everywhere else but the Soviet Union—had to round-file that kind of dream. For much of the space program's first 20 years, those kids knew that your name had to be either Yuri or John if you were ever going to get into space.

Lucky for them, things changed in the last decade, as the Soviets and Americans tried to win friends and influence trade partners by offering orbital rides to astronauts from favored nations. Starting with the first Intercosmos mission in 1978, the Soviets flew not one but thirteen close personal friends, getting a jump on NASA's plans to offer shuttle lifts to those on its own Good List—including some countries which otherwise would have had a snowball's chance in re-entry of launching their own people.

Today's list of "ticketed" passengers on upcoming American and Soviet spaceflights includes a German, Briton, Swiss, Italian, Austrian, Japanese and Canadian—all of whom are scheduled to make it into orbit between now and 1992 (see page 44). Rather than just joyriding, however, these international astronauts will be logging on-orbit time with a plan in mind. They'll be going for all the training they can get, choosing the best elements from the Soviet and American programs, while building their own home-grown astronaut corps in preparation for the opening of the international modules on space station Freedom in 1998. The European Space Agency (ESA) plans to have its new astronaut training center in Cologne, West Germany ready by 1993. And if the new Hermes spaceplane holds to schedule, European astronauts won't have to hitch a ride into orbit come the next century.

The age of the international astronaut is about to begin.

Not that some haven't gotten a head start. Ulf Merbold, a 49-year-old West German physicist who defected from his native East Germany back in the days when you still had to, was the first non-U.S. citizen to fly on the shuttle in 1983. Now training for his second shuttle mission in December, Merbold is typical of the half dozen or so Europeans who have gone into orbit as shuttle "payload specialists" in charge of a specific experiment or set of experiments.

Ironically, one thing ESA won't duplicate in its own astronaut corps is the payload specialist position. Intended at first as a classification for "temporaries," NASA shunted almost all the non-U.S. flyers into PS jobs, along with industry experimenters, Congressional observers and visiting princes. Word was that the PS position was for amateurs, a brand that rankles non-U.S. scientists making a career in space.

Wubbo Ockels is a Dutch physicist who flew for West Germany on the 61-A shuttle mission in 1985. Like Merbold, he is classified as an ESA astronaut, but he has trained with NASA to become a "mission specialist," which means he's been given a more thorough knowledge of shuttle systems. On his 1985 Spacelab flight, though, Ockels was "just" a payload specialist.

"I became very good friends with many astronauts," he says, "but at times there was a certain amount of 'tribal attitude' or protectionism. One issue is whether or not you're a NASA astronaut. The other is, are you a mission specialist or a payload specialist?"

Scientists making a one-time spaceflight connected with a specific experiment may be able to accept second-class citizenship. It doesn't go down so easily, though, when you *are* a career astronaut

Euro

NUNO VIEIRA/DLR

West Germany's five new astronauts were selected from 1,799 applicants who answered a newspaper ad. Standing, from left: Hans W. Schlegel, Ulrich Walter, Renate Brümer. Kneeling: Heike Walpot, Gerhard Thiele.

and *did* have to compete for your job.

"[French 'spationaute'] Jean-Loup Chretien came to the U.S. to train, already a flown cosmonaut and a pilot in the French Air Force before that," says Ockels. "The Russians treat you as one of them as soon as you get in the gate. But especially in Houston, that's not the case with the Americans. He was treated as a non-existent, foreign, payload specialist *backup,* and so has a very negative opinion."

However bruising to the ego, one benefit from the guest flights of the past decade has been the chance for Europeans to compare U.S. and Soviet training styles. Talking with those who wore a Red Star in the 1970s and 1980s, it seems that flight prep in the Soviet Union varied from two years of top-quality training to "here's the relief tube and here's what you don't touch."

The training the Soviets gave to French spationautes was more detailed, according to Soviet-watcher Nicholas Johnson of Teledyne Brown Engineering, while instruction given to Warsaw Pact and Third World cosmonauts was "pretty much bare minimum. The story goes that many years ago, when Chretien first trained, they tried to pull that on him and he wouldn't buy it at all."

That's probably because Chretien didn't consider himself a participant in a Soviet publicity stunt, but a full-time, professional astronaut. He spent a total of five years in the Soviet Union, and flew the Soyuz T-6 mission in 1982 and TM-7 in 1988. Chretien skirts the question of how he got the Soviets to give him the full-up cosmonaut training, but is definite that what he *did* get was as complete as what Moscow's career fliers were receiving.

He also had the chance to experience American spaceflight training during the 10 months he spent in Houston [as backup to Patrick Baudry's 51-G shuttle mission in 1985]. "There is a slight difference in the training methods. In Russia the lessons are given like in high school, morning to evening, and you write and hand in assignments. In Houston you had more time to read books on your own."

With astronauts like Merbold and Chretien having blazed the trail for international crews, a new generation of Europeans, Japanese and Canadians are being treated less like guests, and more like colleagues—or, at the very least, like good customers. The Soviets, who used to fly international guests for free, are now charging some $10 million a seat to countries

nauts

like West Germany, Japan, Austria and Great Britain, all of whom have passengers booked on Mir between now and 1992.

Canadian, European and Japanese scientists, meanwhile, will have new opportunities to work alongside their NASA colleagues in orbit beginning in December, when flights of the European-built Spacelab module resume. Six Spacelab/shuttle flights are scheduled for the next two years alone.

The five Germans now in training for both a 1992 Spacelab mission and a Mir flight are typical of the new breed of professional astronaut. All have impressive resumes, with degrees and scientific publications by the fistful. Three are physicists, one a doctor and one a meteorologist. All have their private pilot's licenses.

Not all the prospective passengers are planning to make a career in space, however. Two Britons are currently wading through schoolwork in a Star City classroom, hoping for a single 1991 flight on Mir—that is, if the commercially sponsored "Juno" project can raise enough money to pay their fare (as of early May, the chances appeared slim). In the classroom next door are two Japanese journalist-cosmonauts who've also reserved a seat onboard Mir in 1991.

In an interview in the British Interplanetary Society's *Spaceflight* magazine, Juno astronaut Timothy Mace described the rather pedantic syllabus through which he and his partner Helen Sharman have been gamely plodding. From December to March they spent days and evenings studying Russian with an instructor who speaks no English. From there it was off to another classroom for classes in aeronautics and medicine. The lecture-heavy schedule allowed them time for only two excursions into nearby Moscow in four months.

Language is an important and somewhat touchy question for foreigners training at American and Soviet space centers. Claiming crew safety considerations, both countries demand high levels of proficiency, and conduct all the training and in-flight operations exclusively in English or Russian. The Soviets provide exhaustive language training in Star City, however, while NASA requires English fluency before the guest even arrives.

Making the leap from Japanese to English can be a linguistic nightmare, and Japan's space agency NASDA hired a private language school for three years to tutor payload specialists preparing for a 1991 shuttle flight. The Japanese also sent each PS for 20 months of "potential improvement training" at separate research centers in the States.

Along with all the language and science training comes an indoctrination into each agency's philosophy and protocols for teamwork and chain of command. The Russians serve up generous doses of after-hours comradeship and familial warmth in the college-like cloisters of Star City, according to Mace.

Guests in the United States, meanwhile, learn how NASA people knot their neckties and drink their tea while on the job. Charlie Walker, a "foreigner" who's

Dutch physicist Wubbo Ockels (below, left) flew on a U.S. shuttle mission in 1985. Swiss scientist Claude Nicollier (center) tries out a life raft in training for his shuttle flight in 1991. British journalist Clive Smith (right) undergoes a g-load test, preparing for a possible mission on Mir.

ESA

NOVOSTI

Who's on Deck?

Canada's Roberta Bondar will become that country's second space traveler when she flies as a payload specialist on the International Microgravity Lab (IML-1) shuttle/Spacelab mission in December. The 44-year-old neuro-opthalmologist is also a glider pilot and championship skeet shooter. One of six Canadian payload specialists, she'll be the first non-U.S./non-Soviet woman in space.

Ulf Merbold became West Germany's first astronaut in space on the STS-9 mission in 1983. He'll fly again on the International Microgravity Lab mission in December. All told, Germany has eight astronauts, including shuttle veterans Merbold, Reinhard Furrer and Ernst Messerschmid. In 1988 five more, including Heike Walpot, the space program's first Olympic swimmer, were chosen as "science astronauts" from among 1,799 applicants who answered a newspaper ad. Walpot and her new colleagues—Gerhard Thiele, Renate Brummer, Hans Schlegel and Ulrich Walter—are undergoing a full program of training in Germany. One will be chosen for an eight-day $9-million flight on the Soviet Mir station in 1992, while two others will fly on a German-U.S. Spacelab flight in May of that same year.

Japan's Mamoru Mohri was chosen recently from among three Japanese payload specialists for a June 1991 shuttle/Spacelab flight. The 42-year-old native of Hokkaido earned his Ph.D. in Australia and taught nuclear engineering for 10 years before joining the Japanese space agency NASDA. Following that, he put in a year and a half of payload specialist study at the Center for Microgravity & Materials Research in Huntsville, Alabama.

Flying for the Red Team will be one of the TBS broadcasting company's "Cosmo-

flown as a private industry payload specialist for McDonnell Douglas, says that the 16 months training for his three shuttle flights specifically included simulation exercises and other opportunities to "get acquainted" with his crewmates in a work situation. One of NASA's great strengths, he says, is "working as a team."

Creating a team spirit is on the minds of several space agency directors around the world these days. Japan's three payload specialists are the nucleus of an astronaut corps intended to fill slots on space station Freedom, of which Japan will be a 13 percent owner. Canada's space program is moving to a new headquarters near Montreal as it prepares for its own space station operations.

The group with the biggest plans is ESA, which intends to beef up its existing astronaut corps to 40, in preparation for the Columbus space station module and Hermes shuttle. A call for new astronauts will be launched "based on NASA requirements," says Walter Peeters, Belgian head of the astronaut coordination office at ESA's new Crew Training Center in suburban Cologne, Germany. "Preselection will be done by ESA member states, and we hope to have at least one from each member nation. The idea is to have the first group by the end of 1991, then a second by the end of 1994. We think that Hermes will need two crews of three each year, and the space station is a question mark right now."

"There will be two categories," Peeters adds. "Lab Specialists would be like the PS on Hermes and Columbus, and Space Plane Specialists would be commander and pilot on Hermes. The latter would have to be pilots with three to five years experience, but we're not sure if they'll have to be military test pilots. We're trying for a nice mix of people in physics, life sciences, etcetera."

ESA politics demands that paybacks be doled out in proportion to the contribution of each participant nation. Accordingly, the German space agency DLR will coordinate and conduct much of the training, but parts will be handed off to facilities in other countries.

The $32 million facility itself will be an add-on to the existing DLR training center in Cologne, where Germany's eight current astronauts are preparing for upcoming U.S. and Soviet flights. Construction is scheduled to take until 1993, with procurement and preparation lasting through 1994. Training should begin in 1993.

Once the European astronaut center is up and running, the average training time is expected to last four to five years. The astronauts will train in full-scale mockups of Hermes, the Columbus space station module, and a free-flying "man-tended" module. Also on hand will be the staples of NASA astronaut training—simulators, offices, conference rooms and the like.

In addition, says Peeters, "Centers of expertise will be established: pilot training in Brussels, robotics in Nordwijk [Netherlands] and some underwater train-

continued on page 60

Japan's Mamoru Mohri (below, left) will fly on the shuttle in 1991. Japanese journalist Ryoko Kikuchi during a forest-landing survival test with Soviet cosmonaut Anatoli Artsebarski. West German Ulf Merbold (right) became the first European astronaut to fly on the space shuttle in 1983.

NASDA

NOVOSTI

ESA

Reporters," either Toyohiro Akiyama or Ryoko Kikuchi, who are training for a paid 1991 flight on the Soviet Mir station. The 47-year-old Akiyama has given up his four-pack-a-day habit "voluntarily" (according to his employer) to better face the rigors of space training. A former Washington Bureau Chief for the Japanese network, Akiyama was chief editor of the foreign news division before applying to deliver live TV and radio broadcasts from orbit. Camera operator Kikuchi's off-time activities—mountain climbing, cycling, skiing, basketball and swimming—have helped her withstand the 36-hour snow survival training test and parachute jumps that are part of cosmonaut training.

Italy's three payload specialists are in training for a Tethered Satellite System experiment, which will be deployed from the space shuttle in September 1991. Unreeling the mile-long spaghetti in space will be either Umberto Guidoni, Franco Malerba or Cristiano Cosmovici. A native of Rome, the 36-year-old Guidoni's specialty is thermonuclear fusion. Cosmovici, 47, has led research into the formation of complex organic molecules in comets and also plays the violin. Malerba, 43, is a physicist.

Switzerland will launch its first astronaut, Claude Nicollier, on the STS-46 shuttle mission in September 1991, which will test the new European Eureca free-flying spacecraft, along with the Italian tethered satellite. The 45-year-old Nicollier will also be Europe's first shuttle "mission specialist" to fly. A former Swissair DC-9 pilot, he holds a masters' degree in astrophysics from the University of Geneva and plays the Alpenhorn. He's been training in Houston for 10 years, but still goes home several times a year to put in his flight time with the Swiss Air Force.

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SPACE CAPSULES

A record of space-related events, March-May 1990

March 4

Space shuttle Atlantis landed in California after a four-day secret military mission. Newspaper reports quoted intelligence sources as saying that the billion-dollar spy satellite deployed during the flight suffered a terminal failure less than a week later and re-entered the atmosphere. The Pentagon confirmed only that certain "objects" taken up by Atlantis were tumbling back to Earth.

March 8

The United States and Soviet Union agreed to cooperate on the Soviet Radioastron mission scheduled for launch between 1993 and 1995. The satellite, equipped with a 33-foot radio antenna, will study astrophysical objects from Earth orbit. The United States will help with tracking and data analysis, and American scientists will help plan the overall mission.

March 13

The Magellan spacecraft successfully executed the second of three "mid-course corrections" designed to keep it on target for an August rendezvous with Venus. Since Magellan's launch in May 1989, ground technicians have been dealing with a number of annoying problems, none of them particularly serious or threatening to the mission. Temperatures on parts of the spacecraft have been higher than normal, and its solar panels have degraded more than expected due to some of the strongest solar flare activity ever recorded. When it reaches Venus on August 10 (after a looping, 800-million-mile journey), Magellan will undergo checkouts in orbit for about 20 days before beginning its eight-month mission to map the planet's cloud-covered surface with radar.

Infrared picture of the Milky Way galaxy and its central bulge, taken by the Cosmic Background Explorer (COBE) from Earth orbit.

March 14

A wiring error on a Titan 3 commercial rocket stranded an Intelsat 6 communications satellite in a uselessly low orbit around Earth. NASA and the Intelsat organization immediately started working out plans for a shuttle rescue mission, which NASA says it could fit into its schedule by 1992—that is, if Intelsat is willing to foot the bill.

March 19

The European Giotto spacecraft, which already made one flyby of a comet (Halley) back in 1986, was re-targeted by ground controllers for a second cometary encounter in 1992. The battered probe's new orbit brings it within 14,000 miles of Earth on July 2. If onboard cameras and other instruments are deemed reliable enough, the resuscitated Giotto will meet up with comet Grigg-Skjellerup in July 1992.

March 19

Japan became only the third nation to put a satellite in orbit around

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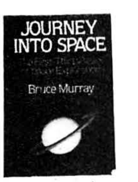

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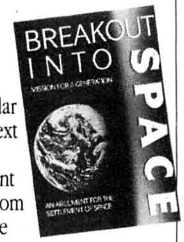

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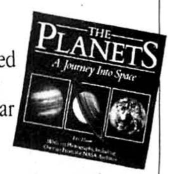

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the Moon when the tiny Muses-A spacecraft was placed into a 10,000-mile-high lunar orbit after separating from a larger spacecraft launched into an elliptical Earth orbit in January. The basketball-sized orbiter is meant as an engineering test for more advanced lunar satellites.

March 25

The seventh satellite in the U.S. military's Global Positioning System (GPS) network was launched on a Delta rocket from Cape Canaveral. A total of 21 GPS satellites will be in orbit by 1992, providing extremely precise navigation and position-finding data to ships and other vehicles on the Earth's surface.

April 3

Rockwell International and NASA announced the signing of a commercial agreement whereby the company will market an Extended Duration Orbiter (EDO) capability to paying customers. By adding extra fuel and other supplies, EDO "kits" could stretch shuttle missions to last as long as 28 days.

April 3

Israel took another step into the space age with the launch of its second satellite, Ofek-2, from a site in the Negev desert. The 352-pound experimental spacecraft, which is similar to the first Ofek launched in September 1988, was placed in an elliptical orbit.

April 5

The long-awaited first flight of Orbital Sciences Corporation's Pegasus rocket went off without a hitch. Minutes after its release from under the wing of a NASA B-52 aircraft piloted by former astronaut Gordon Fullerton, the Pegasus delivered its two small satellites to polar orbit. OSC hoped the launch would help to open up a new market for small satellites. By month's end, the company had gone public with 2.4 million shares of stock, which were selling for $14 a share.

April 7

A Chinese Long March rocket lofted the Asiasat communication satellite into orbit for a paying customer, marking China's entry into the commercial launch business (see page 37).

April 7

Apollo 17 astronaut Ron Evans died at his home in Phoenix, Arizona, of a heart attack. The 56-year-old former astronaut had flown on only one space mission, as the command module pilot who remained in lunar orbit while Gene Cernan and Jack Schmitt made the Apollo program's last trip to the Moon's surface. Evans had retired from NASA in 1977.

April 9

An inquiry board looking into the February 22 explosion of an Ariane rocket carrying two Japanese communications satellites identified the culprit as a small piece of cloth blocking a water line in one of the booster's engines. The satellites were worth about $600 million. Ariane launches were set to resume this summer.

April 13

A refurbished Indonesian Palapa satellite was returned to space onboard a Delta 2 booster, four and a half years after American astronauts plucked it from orbit on the space shuttle's first satellite retrieval mission. The launch came less than a week after the other spacecraft retrieved on that November 1984 flight, renamed Asiasat, was returned to space by a Chinese Long March rocket.

April 16

A committee of the National Research Council threw cold water on the idea of a joint U.S./Soviet Mars mission, warning in a report that the United States should be cautious in signing up for any such cooperative projects. The two countries' Mars missions, said the report, should be "highly coordinated" but "independently conducted" for the time being. Pointing to the fact that Soviets and Americans don't have much experience working together, the committee said that limited cooperation now might lay the groundwork for more extensive partnerships in the future.

April 24

Space shuttle Discovery roared into orbit with the Hubble Space Telescope and a crew of five onboard. The telescope was successfully dropped off into orbit on the second day of the flight, and ground controllers immediately set to work with a program of technical check-outs that was expected to last into the summer.

May 11

President Bush finally did what many in the space business had been encouraging him to do for months: He set a deadline for a U.S. landing on Mars. At a commencement speech delivered to graduating students at Texas Agricultural and Industrial University, a largely Hispanic school in Kingsville, Texas, Bush said, "I believe that before Apollo celebrates the 50th anniversary of its landing on the Moon [on July 20, 2019], the American flag should be planted on Mars." Ever since Bush announced in July 1989 that the United States would return to the Moon and go "on to Mars," critics have charged that it was a plan with no specific timetable or means of funding. Now at least the former is no longer true.

Upcoming Launches

June

"Kristall" materials science lab set for launch to Soviet Mir space station.

July

STS-38 space shuttle mission, with a secret military cargo onboard (July 9).

European Ariane rocket returns to flight with a double payload onboard: French and German television satellites (exact date undetermined).

August

STS-40 Spacelab/shuttle mission dedicated to biomedical research (August 29).

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The Human Factor

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tions to medicines are also potential sources of trouble, he says. "In a sense, it's the old problem of the canary in the mine."

Equally important are the psychological aspects of living in a closed environment. "We're learning that when humans are in highly complex, automated systems, problems often arise from human error," says Sulzman. NASA is studying the airline industry for hints on selecting and training crews that work well together, and looking forward to the day when astronauts can rack up months at a time onboard Freedom to learn more about these problems.

Perhaps the greatest hazard for long-term space travelers will come from radiation. Unfortunately, that's something the space biomedical establishment now knows relatively little about.

Space travelers are subject to two kinds of radiation. The first comes from solar flares, which could cause radiation sickness and death in unprotected astronauts. The frequency of these flares varies over an 11-year cycle, so missions could be timed for solar minimums. But NASA would still need to develop a warning system and include some sort of shelter on the Mars ship to protect against unexpected solar flares. The shelter would typically have some 10-15 inches of metal shielding. Unfortunately, even light metals like aluminum would add up to 30 tons to a spacecraft's weight. (The Apollo astronauts didn't carry that much shielding, but theirs was a shorter voyage.) Another possibility would be an electromagnetic "shield" generated around the ship.

A second, less well-understood danger is cosmic radiation, which comes in many forms, including heavy particles that originate in the cores of distant stars. While the Earth's magnetic field protects astronauts in low orbit (and all of us on the ground) from most cosmic radiation, voyagers headed for Mars will have to deal with it, including the variety known as high-LET (Linear Energy Transfer) particles.

Scientists know that high-LETs are dangerous to humans—they're just not sure exactly how much damage they can do in comparison to low-LETs such as x-rays or gamma rays. When high-LET particles hit solid matter, they fragment and create a stream of radiation. Getting hit with a low-LET particle is analogous to being hit by a BB. A hit with a high-LET particle, on the other hand, is closer to the effect of a shotgun blast—several hundred pellets hitting at once, says Gary Strniste, deputy group leader in genetics at the Los Alamos National Laboratory.

"We're still trying to ascertain how cells respond to this. We envision that it would be much more catastrophic," he says.

Researchers at Los Alamos, in collaboration with others, are using particle accelerators in their efforts to study the effects of high-LET radiation. But as yet, says Strniste, "There's very little data for some of the charged particles we're going to experience in space."

Complicating matters is the fact that it's very difficult to shield against high-LET particles: One problem is that, as the particles pass through the shielding material, they may fragment and create secondary radiation, says Holloway. Also, shielding that works against heavier or more energetic particles is ineffective against lightweight radiation such as gamma rays. And the thicker and heavier the shield, the more fuel it takes to get your spacecraft to Mars. "It's a tradeoff," says Strniste. "You're not going to minimize the radiation flux to zero."

At Los Alamos and other labs, researchers are working on at least one alternative to shielding: protecting humans against radiation by manipulating or repairing DNA. Researchers have isolated some of the genes that recognize and repair DNA damage, says Strniste. In the next century, we may learn how to "turn on" the repair mechanisms. Gene research might also lead to a way to screen out people who are more sensitive to radiation damage (meaning an otherwise perfect candidate could some day be turned down for a Mars flight due to bad genes).

Just how much radiation astronauts should be subjected to is a matter of debate: NASA recently relaxed its guidelines for limits on annual and career exposure to radiation. Depending on the age and sex of the astronaut, exposure is now limited to no more than 100 to 400 rem (roentgen equivalent man) over the course of an astronaut's career.

The limit is lower for women astronauts than for men, since women don't create new eggs the way men create sperm. Also, the earlier the astronaut starts his or her career, the lower the limit. These numbers apply only to flights in low Earth orbit, and not, for example, to a Mars mission, says Sulzman. Standards for those trips have yet to be developed and will probably be lower, he says.

With the current standards, an astronaut could be exposed to 50 rem a year, even with shielding, says Francis D. Moore, Moseley professor emeritus of surgery at Harvard, who also serves on NASA's biomedical advisory board. That compares to the five rem a year that nuclear submarine workers are allowed, and the 0.1 rem a year limit considered tolerable for the general population. Moore thinks that makes radiation a show-stopper for human expeditions to the planets. "My point is simple," he says. "That's too much. We should explore the Moon and Mars with robots."

Most others disagree, saying that we need more research before making any such decision. Holloway even compares the risk of a Mars mission to risks taken by explorers in previous eras: "Columbus lived in a world in which bubonic plague occurred every 75 years; in which syphilis was just about to appear and sweep Europe for the first time; in which people at sea died of scurvy and traveled in horribly inadequate boats for supporting life. Crowding was a huge problem. The Nina was just about the size of my office and my secretary's office—and these are not large offices. They sailed with a crew of about 22."

Magellan, he continues, set out to sail around the world with a crew of 500. The voyagers made it, but with only 35 crew members left. Magellan was not one of them.

Will 21st-century astronauts, traveling on government-funded missions to Mars, accept the same level of risk? Probably not. But it puts things in perspective, says Holloway. "The problems facing Columbus in deciding to come to the U.S. were considerably worse biologically than the problems facing a flight to Mars." □

Devera Pine is a freelance writer and editor in Baldwin, New York. Her article on Robert Farquhar appeared in the November/December 1989 issue.

Telepresence

continued from page 31

inside, here is a hint from Gibson's book:

"Please, he prayed, Now—
A gray disk, the color of Chiba sky.
Disk beginning to rotate, faster, become a sphere of paler gray. Expanding—
And flowed, flowered for him fluid neon origami trick, his country, transparent 3D chessboard extending to infinity. Inner eye opening to the stepped scarlet pyramid of the Eastern Seaboard Fission Authority burning beyond the green cubes of Mitsubishi Bank of America, and high and very far away he saw the spiral arms of military systems, forever beyond his reach.
And somewhere he was laughing, in a white-painted loft, distant fingers caressing the deck, tears of release streaking his face."

Whoa!

VPL's Laskko-Havrill, like just about everyone else in the field of virtual reality, is familiar with Gibson's book and its frightful picture of the social consequences that might result when corrupt businessmen and nihilistic hackers get deep into exploiting the digital wealth of cyberspace.

"I often think of his book as sort of a cautionary tale of some of the downside that can happen with this technology if we aren't careful about how we use it," she said. "But I don't think he's a prophet of what will happen, hopefully." ☐

Grant Fjermedal is the author of The Tomorrow Makers *(Tempus Books), which was named to the American Library Association's annual list of 10 Notable Books of Nonfiction.*

Driving FTS

continued from page 31

structure. On the video monitor, you can see the six gyros, covered up with glittering metallic sheets that protect them from meteorites and the harsh temperatures of space.

The computer screen clears, then prints, "CMD CMGPLT 001: Attach FTS to worksite...proceed?" After checking the graphics overlay on the video monitor, you decide that everything looks "nominal" and hit the return key again. Freedom's arm gently positions FTS near an attachment fixture next to gyro number four, plugs it in, detaches from the robot and waits.

Now, FTS is sitting on its "tail" on the side of the pallet, waiting for someone to tell it what to do.

Here's where it gets interesting.

You strap your right arm into a shoulder restraint near a hand controller, and use your left to hit a few keys until the correct menu comes up. Then you select "Teleops with force reflection"—meaning that you'll feel what FTS "feels," at least to a crude approximation. Intently, you study the screen as you nudge and caress the hand controller. The robot's right "arm" is following your commands as you gently lift and rotate the thermal covering off of gyro number four.

While you've done the same job more than 50 times in the simulators, this is space...and everything you do now counts for real. Finally, after a few minutes, the fragile cover is off...safely connected to a temporary restraint. Pulling your arm out of the holding straps, you command the computer again.

"CMD CMGPLT 0004: Detach gyro number four."

Now operating on its own, FTS stabilizes one of its arms against the pallet and begins unbolting the gyro with the other. You're just an observer now, slightly bored, watching the graphics overlay and video screen for any problems. On the console is a large red button labeled "EMERGENCY STOP," but it doesn't look like you'll need it tonight.

The six-foot-long robot methodically goes about unhooking the gyro, then slowly lifts it out of place and automatically positions it above its "head" and stops—the ultimate bench press with a 600-pound gyro that weighs zero in orbit. At that moment, the Sun rises over the Earth's horizon and sends beams of light across the station, casting long shadows across the truss structure.

Again you go into "teleops," securing the thermal cover.

The electronic banter continues between you and the computer while you use the FTS to replace the failed unit with a new gyro. Finally, after several hours, you're finished. The failed gyro's been stored for a later return to Earth, FTS has been stowed, and you've called Houston to tell them the job's done and everything's working normally.

It's over. Now back to bed. ☐

Launchers

continued from page 40

way the Australians can amortize the $400 million cost of building a new launch complex is to leverage its entry with cheap rockets, officials argue. So the final market price of a Cape York launch might be twice the cost of buying the rockets from the Soviet Union, one officer explained.

But even at double the rate, the Zenit could seriously undercut the Titan's $100 million to $125 million price tag, Atlas' $65 million tab or even the Delta 2's $45 million to $50 million sticker price.

And there's not a thing the United States can do about it.

An American company called USBI, a subsidiary of United Technologies, is even looking to manage development of the spaceport Down Under. The company asked the U.S. State Department last fall for permission to transfer its technical know-how to Australia. Ordinarily, that wouldn't seem a problem, since the Australians are close allies and belong to a consortium of nations committed to safeguarding Western technology from the Eastern Bloc. The wheels were greased for quick approval of the plan.

But they ground to a halt after smacking into an impressive phalanx of lobbyists from General Dynamics and others in the U.S. domestic launch industry, who asked the Bush administration to give the USBI deal a second look. One administration official who saw things their way said Cape York is "not so much a spaceport as it is an Australian site from which to launch Soviet rockets."

A White House official even took the Machiavellian view that what the Australians were *really* up to was testing whether they could win export licenses for U.S.-made satellites by choosing an American launch manager.

Were the Australians just sticking their toe in the water, or have they already taken the plunge? Most bets are on the latter. Bruce Middleton, head of the Australian Space Office and as much an advocate for his country's space industry as Lee-Miller is for hers, said, "I think the [Cape York] spaceport will happen, and if the U.S. is not involved, I'm sorry."

Ironically, as more countries are getting into the game, the pool of potential satellite customers may be shrinking. There may be as many as 20 or as few as a dozen launches annually in coming years. The rise of fiber optics as an alternative to satellites in developed countries, and the inability of less developed nations to finance dedicated satellite systems, means that launch companies will have to fight even harder for fewer fares.

Sam Mihara, staff director of the Delta Launch Vehicle Division at McDonnell Douglas, says, "Clearly, the market is going down and the number of suppliers is going up. That's a very uncomfortable situation to be in."

However, Mihara says that every launch is worth fighting for, because, since the U.S. government is only good for three or four contracts a year, "adding another one or two commercial launches is a significant percent of our total business."

Another difficulty, in terms of U.S. trade policy, is that what serves the launch industry may be bad for satellite builders. Companies like Hughes stand to lose if foreign customers, prevented from launching U.S.-made satellites on low-priced rockets, start shopping elsewhere for their spacecraft.

"It's the problem of the Berlin haircut," says Musarra. "You can get one for $4 in the East and $12 in the West. Questions of quality aside, do you risk heightening international tension by erecting protectionist barriers? Or, do you open the markets and hope everything will level out? Open markets with *fair* competition is our goal. It's getting there that's the problem."

Meanwhile, says General Dynamics' commercial chief Charlie Lloyd, the United States doesn't even know what its next generation of launch vehicles will look like. He points to newer, larger satellites now on the drawing board, to space station Freedom and to plans for the Moon and Mars as evidence that new launchers will be required.

"It's clear to us we need to upgrade our vehicle, to participate in government-funded development of a new vehicle, or join up with another player to be competitive," Lloyd says. His company's preference would be to participate in government-funded efforts to modernize and upgrade current launch systems, as General Dynamics already has spent or has committed $400 million through the end of next year, just

to keep its foothold in the market.

But team with another player? Could any of the "Big Three," each with hundreds of millions invested in their own launch businesses, seriously contemplate joining up with their U.S. rivals, or with Arianespace? Ariane, for one, doesn't seem too keen on the idea.

What might work is a team effort by U.S. rocketeers to design the Advanced Launch System (ALS) proposed by NASA and the Air Force to drastically reduce the cost of reaching Earth orbit. Such teaming already has taken place among National Aerospace Plane (NASP) contractors.

"When I saw that in the papers, I clipped it," says Janice Bellucci, aide to Congressman Bill Nelson's space subcommittee. "But I didn't file it under 'NASP.' I put it with my commercial launch material. Why couldn't the same thing work in designing ALS?"

But hear what a launch *customer* has to say about it. In congressional testimony late last year, C.J. Waylan of GTE Spacenet warned against parochial solutions to America's loosening grip on the space business.

He said his decision to choose Ariane to launch his satellite was based on reliability, schedule confidence, and finally price. Any solution the government devises should help both space industry sectors, he says, or the United States risks putting satellite manufactures in the same boat that rocketeers are in now.

"We in the U.S. must not remain so aloof or arrogant concerning space," Waylan says. "We are no longer a clear leader across the board.

"The situation could be likened to the 1970s auto industry. In that industry, too, a crisis was required to bring us to realize that our market concepts and technology were not meeting market demands. It took years for U.S. companies to turn their directions and respond with the quality and economics users were requiring."

But rocketeers may not have a decade to fix their problems. Says Mihara, "If we don't solve the launch vehicle problem today, we'll have the same problem with satellites tomorrow." □

Melinda Gipson is the editor of Space Business News. *Her article on small satellites appeared in our January/February 1990 issue.*

Onboard Freedom

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not the funds), NASA engineers have been mercilessly riding their CAD/CAM programs in an effort to whip up a space station that fulfills the demands of its proposed role while not ruffling too many scientific, political and international feathers. (The role of the United States' international partners in the station's next phase remains an open question.)

Lewis Peach, NASA's deputy for space station engineering, looks this monster in the face every day, but he says he does it joyfully. "It's fun...but it's extraordinarily difficult." The plan Peach and his colleagues have prepared over the past several months is an impressive example of applying, on a grand scale, the laws of evolution to the headaches of orbital engineering.

Should Congress decide to spring for the billions necessary to begin expanding Freedom, real changes would get underway (according to current NASA timetables) on the day a shuttle gingerly docks with the station just three years after Freedom reaches its first (Assembly Complete) phase in 1999. Throughout this next expansion period, Japanese, European and American astronauts will continue to labor in their own laboratory modules—NASA guarantees that even as the station grows, these activities will continue without interference. And various shuttles will continue to routinely supply food, water, fresh crews and new experiments.

But the ship that arrives on this particular day in 2002, at the dawn of a new era for Freedom, won't be hauling provisions. It will be crammed with the first of Freedom's expansion kits.

Shortly after arrival, with the help of the shuttle "arm" and the station's own robotic corps of engineers—the large Mobile Servicing System and the smaller Flight Telerobotic Servicer—two astronauts will begin reshaping Freedom for its role as a Moonport. First, they'll assemble and attach a boom and two lower keels onto the station, forming an enormous rectangle. Within the embrace of these supports, the first reusable Moon ships will be assembled, tested and serviced. Several more shuttle flights will be needed before astronauts and robots finish off this new lower section, add a construction pallet and attach a dock for an unmanned space truck: probably a shuttle-like cargo craft (called Shuttle-C) that can ferry up heavier payloads.

Workers also will begin sprucing up the station's original supporting truss, adding radiators to shed heat, and more propulsion engines to provide an extra boost when the growing station's orbit decays. Two umbrella-shaped solar dynamic power plants will also be fixed to the truss, one on each end, to bolster the station's overall power from 75 to 125 kilowatts. Finally, a pressurized resource node will be attached to the lower end of the station's laboratory module—living quarters for Freedom's two new full-time crew members.

With these additions complete, astronauts will begin assembling (on a platform unshielded from cosmic debris) the craft that NASA has dubbed the Lunar Transfer Vehicle (LTV). The LTV will take humans and some material to the lunar surface in order to establish a base

there; but a second, similar craft called an LEV, or Lunar Excursion Vehicle, will also be constructed. The robotic, expendable LEVs will be like interplanetary mules, designed exclusively to ferry food, fuel and building supplies to the Moon even before humans arrive.

Though the engineering and rocket design of both craft will be loosely based on the old Apollo ships, they won't resemble them much. Not including its engines, the LTV will rise nearly 70 feet (about the same as the wingspan of the space shuttle) and be outfitted with enough room for four crew members to make the three-day lunar journey in relative comfort. At one end will be bug-like legs for touching down on the Moon; on the other, an aerobrake 40 feet wide for slowing the returning ship in the Earth's atmosphere before its delicate rendezvous with Freedom.

Or so goes the plan. The problem with the LTV is that it's untested, and for that reason it won't be making any trips to the Moon until a crew of astronauts is shuttled to the station to take it out for a test drive.

One main reason for the test is to put the LTV's aerobrake through its paces. NASA is pinning a lot on this technology, which could cut the weight of both lunar and Martian ships almost in half. Traditionally, retro-rockets have been used to maneuver ships into orbit, but that requires lots of weight in the form of fuel. Aerobrakes could save tremendous amounts of money, space and fuel—if they work.

"The problem is, the aerobrakes are large," says Peach. "And right now we don't know how to build one that can deploy itself. So it would have to be assembled in orbit."

That's the main reason why the bays for the construction of the LTV, and later the MTV (Mars Transfer Vehicle), will be so large. Only at the space station can the huge frames for the aerobrakes be constructed and fitted with the welded hexagonal tiles that will act as heat shields.

Assuming the first LTV *does* fly, phase two of the station's facelift will begin soon afterwards. At this juncture, the newest visible addition will be a hangar around the LTV's assembly pallet to protect astronauts as they prepare a vehicle that will actually go to the Moon.

But looks alone are deceiving. By this time the inside of the station's new bay will have become a mini-Canaveral, bustling with activity, outfitted with all of the additional computer power, utilities and accessories—including 10 fixed work stations—necessary to repair, modify and maintain the next LTV.

This next Moon ship, the first piloted lunar craft to be constructed on the station, will *not* be reusable. This may seem strange, given that building reusable craft is one of the reasons Freedom is being expanded in the first place. But the plan allows engineers time to redesign the LTV's aerobrake, if necessary, without delaying a manned mission to the Moon. NASA wants such a mission to occur within a year of the aerobrake test.

Whatever the case, NASA hopes that in 2004, with the Earth looming below and the Moon beckoning a quarter of a million miles away, the first LTV will fire its rockets and take humans back to the surface of the Moon for the first time since Apollo 17's

astronauts roamed the lunar regolith in 1972.

The crew of four won't arrive unsupported like their Apollo cousins. Prior to this flight, two cargo ships already will have descended (possibly launched directly from Earth) with a host of goodies. The first will deliver a lunar rover which, with the help of human operators on the station or on Earth, will have chosen a final location for the initial Moon base. The next ship will then drift out of Freedom's lunar assembly bay and rocket to the Moon, where it will leave behind a small habitation module, an airlock and either a solar or a nuclear power plant.

When the crew does arrive, they'll use many of the telerobotic tricks learned on Freedom to operate scientific equipment on the Moon's surface for the next 30 days. Then they'll return to Freedom, recover from their stay and prepare for the trip back home to Earth.

Once astronauts have successfully sown the seeds of a lunar colony, Freedom's crews will immediately begin to further revamp the station, equipping it to handle a routine series of cargo and piloted flights to the Moon—one of each, every year between 2006 and 2015. All piloted flights thereafter will be made in reusable LTVs designed to last at least five years before they're relegated to the junkyard.

This kind of ongoing activity will make Freedom busier than ever. The assembly, maintenance and repair of lunar cargo and crew ships, the preparation and debriefing of crews, and communications between the Moon base and Earth all will keep Freedom bustling. Telescopes, geological equipment and a new pressurized rover for excursions as far as 300 miles away from the lunar base will also have to be ferried from Earth, prepared at the station and launched onward to the Moon—enough to keep even the folks at the Kennedy Space Center in a sweat.

To handle this extra work, shuttles will deliver an additional remote manipulator arm for the lower keel's service track. This arm will be a more muscular first cousin of the shuttle arm, capable of reaching or turning the Moon ships in any position necessary for the ongoing work. It also will pull the ships out of the construction bay so that they can maneuver into launch position.

Finally, NASA will add 50 more kilowatts of solar dynamic power to keep pace with the station's growth, as well as a second habitation module to accommodate Freedom's third new permanent crew member (making 11 altogether now) plus four transient astronauts bound for the Moon.

During the years between 2006 and 2015, activity at the station will kick into overdrive. In addition to its role as an orbiting laboratory and a way station for the Moon, crews will now begin to transform Freedom into a port capable of bidding *bon voyage* to the first humans to visit Mars.

The construction of Mars ships will require the addition of two upper keels and a boom that will mirror the lower ones already added for the Lunar Transfer Vehicles. Like the LTVs, the MTVs will bear no more resemblance to today's spacecraft than the shuttle does to Buck Rogers' ship.

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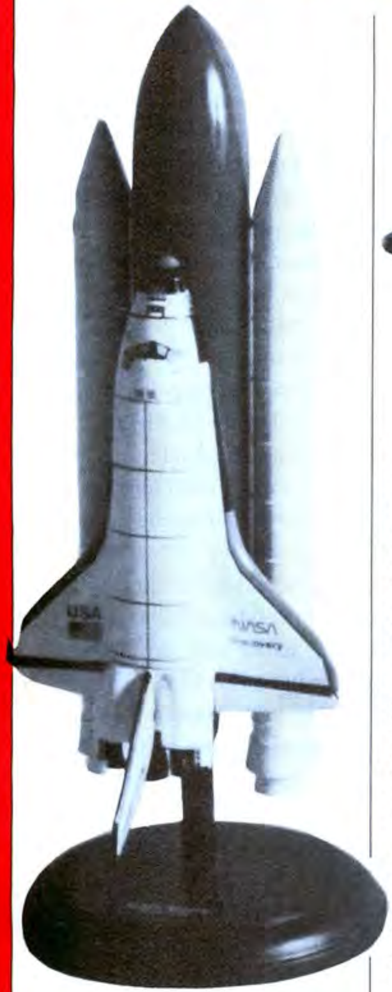

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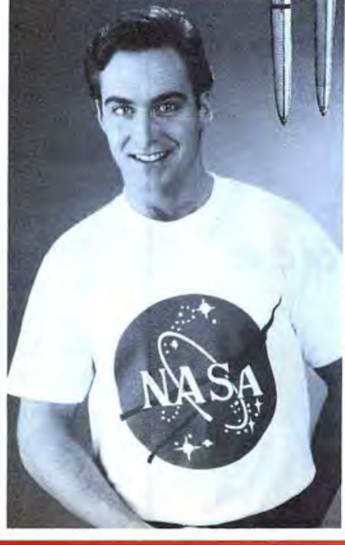

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Onboard Freedom

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you have an idea what the first Mars-bound craft probably will look like. The saucers are the craft's two aerobrakes—one for Mars entry, one for the return home. Crammed like a jack-in-the-box between the aerobrakes will be tanks filled with propellants and supplies; vehicles that will transfer the crew to and from the Martian surface; and living quarters similar to Freedom's habitation modules, where the crew members will, hopefully, pass the 600 days of their round trip without losing a grip on their sanity.

High above Earth, the embryonic Mars Transfer Vehicle will be dwarfed by the enormity of its cosmic surroundings; still, when completed, it will stretch nine stories from stem to stern. To handle the assembly of such a ship and its two gargantuan aerobrakes, additional upper keels and another boom will be added to Freedom. (At last the station will take on the old dual-keel configuration NASA engineers were touting in the mid-1980s.) A second additional robotic arm also will be assembled, and a new crew member will bring the total permanent crew to 12. More computer power will be integrated into the station's system to handle docking, unloading and assembly; and finally, the new service track will be outfitted with cameras to monitor work on the MTV.

This expansion phase will be stretched out for years while engineers on Earth simultaneously design and construct sections of the ship. Even broken down, the unassembled parts of the MTV will be so large they'll have to be ferried to the station aboard heavy-lift rockets such as the proposed Advanced Launch System—big, dumb boosters that will stand nearly 300 feet high and be able to hoist 140 metric tons into low Earth orbit.

As these components arrive, an enormous robotic arm will dock the Hindenburg-sized ships to Freedom and transfer the cargo to the MTV servicing center. Then work will begin. Slowly, over the next several months, robots and astronauts will assemble the pieces, weld the aerobrakes, attach the vehicle's engines and check the spacecraft out, again and again, until finally it's ready for the 70-million-mile journey to Mars and back.

If and when Freedom is transformed into the futuristic spaceport Lewis Peach and his engineers envision, it's difficult to say what the next step beyond *that* might be. Possibly a series of more specialized Earth-orbiting stations or, more likely, structures that will hover at libration points scattered around the Moon and Earth. Given time, who can predict what will happen? Not that some haven't tried.

Perhaps, as some historian in the far future gazes from a desk within view of the spellbinding volcanos of Io, he or she may mark the beginnings of such a feat as the day Freedom began its transformation into an interplanetary spaceport. After all, in order to harness a solar system, you first have to be able to travel around in it and become acquainted with its mysteries.

And you have to start somewhere. ☐

Chip Walter is a Los Angeles-area writer and filmmaker. He begins work on a book about space exploration later this summer.

Euronauts

continued from page 45

ing in Marseilles. We have to share with our member states, and it makes the program that much more appealing to each country's taxpayers."

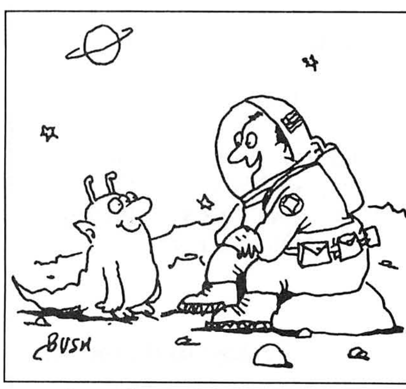
With its ties to Freedom, ESA is leaning toward the American style of training, Peeters says, maybe even down to hiring NASA instructors. "I'm not sure that the U.S. and Soviet training programs are so similar. In the Soviet Union they use a lot of zero-g planes, while in the U.S. they train in [water] tanks. The simulation of weightlessness is better aboard the planes, but training can only be done in 25-second slots."

For the first year or so, says Peeters, ESA will invite experts from various fields, including Americans, to help with the training. "People want to learn from someone who has really been there. Theory is one thing, but you cannot fill someone with a year and a half of theory."

Don Bourque, who coordinates the training of payload specialists at the Johnson Space Center in Houston, feels that one of NASA's strengths is that we've allowed enough insight to the Canadians, Japanese and Europeans for them to really know what we're doing. They understand well that you need to get together a crew that's compatible and put them through their paces.

"We're working as partners, and I'm sure each program will have a lot of cross-pollination." □

Maura Mackowski wrote about early women astronauts in our last issue. Her article on Moon bases in the June 1988 issue won first place in last year's Aviation/Space Writers Association competition.



Sometimes all I need is the air that I breathe.

Who's On Deck

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Great **Britain** is getting four "astronauts" for the price of one. Army Air Corps Major Timothy Mace and research chemist Helen Sharman are training in Moscow for a shot at a 1991 flight on the Mir space station. Mace, 34, trains helicopter pilots for the army and is the current British Freefall Parachuting champion. Sharman, 27, works for the Mars candy company, where, among other duties, she researches the chemical and physical properties of chocolate (a rough job, but somebody's got to do it). The two runners-up in the privately funded Juno competition, Clive Smith and Gordon Brooks, are helping to develop experiments for the flight. Royal Navy physician and deep-sea diver Brooks first volunteered for the job at age 10—he's 34 now—and went on to have his boat shot out from under him in the Falklands war. Smith, 28, is an alumnus of the International Space University 1989 summer session in Strasbourg.

Franz Viehbock and Clemens Lothaller of **Austria**, both scientists, both in their twenties, and both unmarried, were chosen from among 200 candidates to compete for a six-day flight onboard Mir in late 1991, during which they will conduct scientific experiments. Both are currently training in Star City. The Austro-Mir organization that has to come up with the $7 million fee for the flight is thinking of selling ad space on the astronauts' uniforms, and has hired the same marketing firm that promotes Austrian race drivers.

Also preparing for Mir missions in 1992 are as yet unnamed **Spanish** and **French** cosmonauts. Two **Indonesian** payload specialists, Pratiwi Sudarmono and Taufic Akbar, have undergone general training for a future U.S. shuttle flight, under an agreement dating back to the days before Challenger. NASA has not assigned them to a specific flight, and seems in no hurry to do so.

— *Maura Mackowski*

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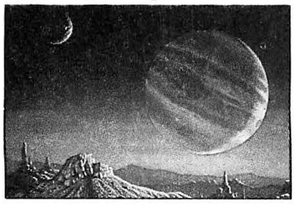

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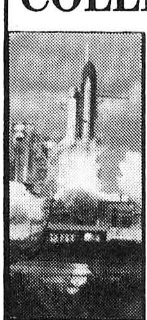
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